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Proceedings for Celebrating the Diversity of Research in the Mammoth Cave Region: 11th Research Symposium at Mammoth Cave National Park

Shannon R. Trimboli Editor

Western Kentucky University, MCICSL, shannon.trimboli@wku.edu

Luke E. Dodd, Editor

De'Etra Young, Editor

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Celebrating the Diversity of Research in the Mammoth Cave Region

**11th Research Symposium
at Mammoth Cave National Park**

Proceedings

April 18-20, 2016

Mammoth Cave National Park Training Center

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Last, but certainly not least, I thank each of our presenters. None of this would be possible without each of you, the valuable research that you conduct, and your willingness to share your work at events such as this.

Thanks everyone!

Sincerely,

Shannon Trimboli

Education Coordinator, Mammoth Cave International Center for Science and Learning



Celebrating the Diversity of Research in the Mammoth Cave Region: 11th Research Symposium at Mammoth Cave National Park

Archeology / History

Civilian and Soldier Graffiti of Hundred Dome (Coach) Cave, Kentucky, 1859 -1862	1
~ Marion O. Smith and Joseph C. Douglas	
Archeological Excavations in Advance of the Historic Tour Trail Rehabilitation	9
~ Steven Ahler and Rebecca L. Hummel	
Documentation and Conservation of the 1812-Era Saltpeter Works in Mammoth Cave, Kentucky	16
~ George M. Crothers and Christina A. Pappas	
New Discovery Cultural Artifact Inventory and Analysis Project Update.....	17
~ David Kime, Jillian Goins, Robert Jensen, Clayton Johnson, Alessa Rulli, and Victoria Voss	
Recent Investigations at 15Ed23: Historic and Cultural Resources in a Disturbed Cave Environment.....	18
~ Joseph C. Douglas, Alan Cressler, George Crothers, Marion O. Smith, Kristen Bobo, and Justin Carlson	
Evaluation of an Early Nineteenth Century Brick Kiln at the Gardner House in Hart County, Kentucky	27
~ Lauren Kenney and Darlene Applegate	
Ethnographic Overview and Assessment of Mammoth Cave National Park: A Progress Report.....	28
~ Michael Ann Williams, Kristen Clark, Eleanor Hasken, and Rachel Haberman	
1852 Journey to Mammoth Cave StoryMap.....	29
~ Katie Algeo	
Mammoth Cave: A Place Called Home	30
~ Cheryl Beckley	
Where Did They Go? An Analysis of Out-Migration from Mammoth Cave National Park During Creation	31
~ Collins Eke	
Flint Ridge Cave History and Legends	32
~ Norman L. Warnell and Stanley D. Sides	
Research and Resources in WKU Special Collections	38
~ Nancy Richey	

Biology / Ecology

The Freshwater Mussels and the Green River: Conservation, Protection, and Management of a Vital Resource in North America	39
~ Monte McGregor	
In Situ Survival and Performance of Juvenile Mussels in Streams and Correlations with Water and Sediment Quality Factors	44
~ Wendell Haag, Jacob Culp, Monte McGregor, James Stoeckel, and Robert Bringolf	
Potential Evidence for Arsenic Mineralization in Mussel Shells in the Upper Green River Basin, Kentucky	45
~ Autumn Turner, Chris Groves, Aaron Celestian, and Albert Meier	
Surveys for the Diamond Darter (<i>Crystallaria cincotta</i>), an Endangered Species Known Historically from the Green River in Kentucky.....	50
~ Matthew R. Thomas and Stephanie L. Brandt	
Host-Parasite Associations of Small Mammal Communities: Implications for the Spread of Lyme Disease	59
~ Matthew Buchholz and Carl Dick	
Bird Research at Mammoth Cave National Park: A Synopsis	60
~ Brice Leech	
The Effects of Rainfall on Vernal Herbs.....	64
~ Janis LeMaster and Albert Meier	
Oak Regeneration in Mammoth Cave National Park.....	65
~ Bill Moore and Carl Nordman	
Conducting a Biological Inventory of Sloan's Crossing Pond.....	66
~ Miranda Thompson, Jason A. Matthews, and Christy Soldo	
Amphibians and Reptiles of Mammoth Cave National Park: What Have We Learned After 13 Years of Monitoring	67
~ John MacGregor	
Over Half a Century of Mammoth Cave National Park Mid-winter Bird Count Data	68
~ Blaine Ferrell	
Video Presentation: Monitoring Cave Organisms, Cumberland Piedmont Inventory and Monitoring Network	69
~ Kurt Helf, Steven Thomas, and Michael Durham	
The Activity of <i>Myotis sodalis</i> and <i>Myotis septentrionalis</i> Changes on the Landscape of Mammoth Cave National Park Following the Arrival of White-nose Syndrome.....	70
~ Rachael Griffitts, Luke E. Dodd, and Michael J. Lacki	

Recent Winter Bat Numbers at Mammoth Cave National Park: Pre/Post White-Nose Syndrome Arrival	76
~ Steven Thomas	
Summary of 2015 Winter Bat Monitoring at Mammoth Cave National Park.....	77
~ Laura Shultz, Chris Clark, Rick Toomey, and Shannon Trimboli	
Evaluating the Energetic Value of Lepidoptera Using Bomb Calorimetry	85
~ Shelby A. Fulton, Luke E. Dodd, and Lynne K. Rieske	
Organization and Development of the Eyes of <i>Ptomaphagus hirtus</i> , the troglobitic small carrion beetle of Mammoth Cave.....	91
~ Markus Friedrich, Jasmina Kulacic, and Elke Buschbeck	
Strip Adaptive Cluster Sampling with Application to Cave Crickets	92
~ Kurt Lewis Helf, Tom Philippi, Bill Moore, and Lillian Scoggins	
The Effects of the Fungus <i>Beauvaria sp.</i> on the cave cricket, <i>Hadenoeus subterraneus</i>	100
~ Christina Walker, Derrick Jent, and Claire Fuller	

Education / Interpretation

Citizen Science at Mammoth Cave National Park: Integrating Research and Education ...	101
~ Shannon R. Trimboli	
Undergraduate Research Projects Help Promote Diversity in the Geosciences.....	108
~ De'Etra Young, Shannon R. Trimboli, Rickard S. Toomey, III, and Thomas Byl	
Youth Engagement in Public Health at Mammoth Cave National Park: A Pilot Alternative Spring Break Program	114
~ Laura Shultz, David Wong, Amy E. Thomas, Rick Toomey, and Shannon Trimboli	
Chronicling Mammoth Cave Data Visualization.....	117
~ Matthew Beckerich, Jared Koshiol, Noah Love, Greta Lowe, Celeste Shearer, and David Kime	
Six Americas: Where Do Teachers Stand	118
~ Jeanine Huss and Cheryl Messenger	

Geology / Hydrology

Drainage to Mammoth Cave National Park.....	120
~ Chris Groves, Katie Algeo, and Laura Myers	
Tracing Carbon in Karst Environments in South-central Kentucky to Identify Changes in Groundwater Dynamic Under Varying Landuses.....	122
~ Chelsea Ballard, Jason Polk, and Kegan McClanahan	

Measurement of Inorganic Carbon Fluxes from Large River Basins in South Central Kentucky Karst	123
~ Connor Salley and Chris Groves	
An Overview of the Reverse Flow Patterns of River Styx in Mammoth Cave, Kentucky: 2009-2012	128
~ Shannon R. Trimboli, Rickard S. Toomey, III, Kim Weber, and Susan Ryan	
Clastic Sediments in Karst as a Vehicle for Contaminant Transport: Lithofacies and Transport Mechanisms	130
~ Rachel Bosch and William B. White	
Green River Alluvial Terraces at Mammoth Cave and Glacial Valley Trains on the Ohio River: Genetic Correlation Revisited	131
~ Joseph A. Ray	
Spatial Distribution Map of Small Caves within Mammoth Cave National Park.....	138
~ Bill Copeland	
The Effect of Faulting on Past and Present Hydrogeology in Long Cave, Mammoth Cave National Park.....	139
~ Rickard A. Olson and Rickard S. Toomey	

Resource Management

Natural Resource Condition Assessment for Mammoth Cave National Park.....	145
~ Cate Webb, Chris Goves, and Katie Algeo	
Meta-Analysis of Research Conducted at Mammoth Cave National Park, 1980-2013	146
~ Andrea Bachman, Nicole Erb, Ellen McPhillips, Matthew Rice, Tawni Riker, and David Kime	
Ongoing Geographic Documentation of the Mammoth Cave System and Related Caves .	147
~ Pat Kambesis and Bob Osburn	
Exploration of Mammoth Cave Pools with Submersible Remotely Operated Vehicles	148
~ S. Altenstadter, O. Hennis, C. Johnson, A. Willett, S. Hammer, and E. Wong	
Redevelopment of Historic Tour Cave Trails	150
~ Rickard S. Toomey III and Steve Kovar	
Quantitative Dye Studies to Evaluate the Spill Response System for Mammoth Cave National Park.....	154
~ JeTara Brown, Thomas Byl, Rickard S. Toomey, III, and Lonnie Sharpe, Jr.	
Continuing Measures in Response to White-nose Syndrome at Mammoth Cave National Park	157
~ Gina Zanarini, Natalie Anderson, Chris Clark, Laura Shultz, Rickard Toomey, and Shannon Trimboli	

Use of Multiphysics Simulation to Model Environmental Conditions Associated with Bat Hibernacula including Preliminary Indication of Impacts on Saltpeter Vats in Mammoth Cave	162
~ Aaron Bird, Rick Olson, Rick Toomey, Aaron Addison, and Rachel Bosch	
Modeling Activity of the Indiana Bat (<i>Myotis sodalis</i>) at Mammoth Cave National Park using Remotely-sensed Descriptors of Forest Canopy Conditions	163
~ L. E. Dodd, N. S. Skowronski, M. B. Dickinson, L. K. Rieske, and M. J. Lacki	
What Data Analytics Can do for You!	166
~ Leyla Zhuhadar, J. Kirk Atkinson, Albert Meier, and Ouida Meier	
The Max Kämper Map of Mammoth Cave - A Centennial Restoration.....	171
~Tres Seymour	

Appendix

Schedule of Events	173
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Civilian and Soldier Names of Hundred Dome (Coach) Cave, Kentucky, 1859-1862

Marion O. Smith and Joseph C. Douglas¹

¹ Volunteer State Community College

Hundred Dome (now Coach) Cave is a complex three mile long grotto in Bald Knob near the east side of Edmonson County and several miles southeast of Mammoth Cave National Park. During 1812-13 it was owned by Williamson Gatewood (b. c.1775) of Bowling Green who mined it for saltpeter. In early 1813, when he offered the cave for sale, it was “in full operation, affording [an] abundance of good dirt” with the furnace “conveniently situated to water and wood.” In addition, there were enough “iron-grates to work 8 50 gallon kettles,” Probably, his brother Fleming Gatewood, a former part owner of Mammoth Cave, managed the operation.¹

By the late 1850s, the cave was owned by John D. Courts (1806-1870), whose father, John, around 1810-12, operated a powder mill in southern Barren County with his brother-in-law Braxton B. Winn. J. D. Courts married a first cousin, Elizabeth Brown Winn, a daughter of Braxton B. Winn, and they had no children. For a time, probably about 1858-61, they had members of a family named Peddicord boarding with them. Included were Wilson Lee (1803-1875), his wife Kiturah B., and two of their sons, Kelion Franklin (1833-1905) and Carolus Judkins (1840-c.1862-63). W. L. Peddicord was a Marylander and a railroad contractor who had lived in Ohio and West Virginia before moving to Sumner County, Tennessee, in late 1856. K. F. Peddicord, born in Belmont County Ohio, also did railroad engineering jobs, and during 1857-58, lived in Nashville while employed by the Louisville and Nashville company. Afterwards, he joined his father in Kentucky to work on the same line.²

While living in Kentucky Kelion F. Peddicord “discovered and explored a number of caverns, the largest of which was the Hundred Dome Cave,” which he perhaps

first began investigating about October, 1859. He, with aid from Courts, “fitted up” the cave “and opened it to the sightseeing public, having carriages to meet the trains for the accommodation of visitors.” There must have been some Kentucky publicity because on January 28, 1860, in faraway Marshall, Texas, the newspapers there referenced it as “recently discovered” and abounding “in geological curiosities.” Three Peddicord names are scratched in Hundred Dome Cave: K. F. and C. J. December 5, 1859, and W. L. with no date. “KFP” is also inscribed in nearby Slave Cave.³

Other 1859 visitors were “A K Bagby Deb [December] 1st” and “R. M. Dolley” next to a Freemason’s symbol. Bagby was Albert Kimbrue (1814-1894), a son of Reverend Sylvanus Bagby and Zarilda Courts, and therefore a first cousin to John D. Courts. He was born in Virginia and moved to Glasgow, Kentucky as a young man, and worked as a master carpenter and furniture maker. His wife was Martha Wooten and they had seven children. A daughter, Mary Alice (1841-1927), in December 1860, became the second wife of Edward K. Owsley (1820-1889), who from 1861 until 1866 was the

proprietor of Mammoth Cave and hotel. Dolley has thus far defied identification.⁴

On January 19 and 23, 1860, Gilbert S. Bailey (1822-1891), a Baptist preacher then residing in Woodford County, Illinois, toured Hundred Dome Cave with K. F. Peddicord and probably others. On his first visit he scratched “G. S. Bailey Metamora Ill” and the date. “J F South Bowling Green Ky Jan 23 1860” and “W H H Mills Jan 1860” are also inscribed on the walls, and possibly they accompanied Bailey. Mills remains unknown but John Fletcher South (1817-1873) was a Warren County, Kentucky, Baptist minister.⁵

The following March 24, in the *Louisville Journal*, Bailey published a long description of Hundred Dome Cave, using at least eighty-four names for internal sites, all presumably assigned by K. F. Peddicord. During his stay in Kentucky he also visited Mammoth and Diamond Caves. Three years later he included descriptions of all three in a booklet entitled *The Great Caves of Kentucky*. The Hundred Dome chapter was very similar to his 1860 *Louisville Journal* article except that the order through the cave is somewhat different and about nine less in-cave place names were used. He also presented a crude map keyed with sixty-one of the cave’s features.⁶

Other 1860 graffiti in the cave includes “R S Courts” and “J D Wickliffe July 7[9?]. Courts is undoubtedly somehow related to the owner, but thus far he is a mystery. Wickliffe could be one of two John D. Wickliffes: a Muhlenberg County farmer (b. c.1799), or a Nelson County lawyer (b. c.1839), more likely the latter.⁷

In April, 1861, the American Civil War began. At first Kentucky tried to remain neutral. But that was untenable and by September Union and Confederate forces

were arrayed against each other inside the state’s borders. Southerners occupied Columbus, Bowling Green, and Cumberland Ford. The Federals took over Paducah, and augmented Kentucky Unionist units by sending in reinforcements from the Midwestern states. On November 9, Kentucky became part of the Department of the Ohio with Brigadier General Don Carlos Buell in command. During the next three months many more regiments arrived from the north, and were primarily distributed to camps near Elizabethtown. More units were stationed at Bardstown, Lebanon, Somerset, and Columbia. The regiments were drilled and assigned to brigades, and brigades were organized into six divisions, all designated the Army of the Ohio. Meanwhile, Confederate forces around Bowling Green gained strength, and by October 13, General Albert Sidney Johnston, head of the southern army in much of the west, moved his personal headquarters there. During these months there was little action, just occasional geographic maneuvering. Part of the Union army advanced to Munfordville on the Green River. The bulk of the Confederates remained at and near Bowling Green, but Brigadier General Thomas C. Hindman maintained a force at Cave City to watch the Federals.⁸

Kelion F. Peddicord and his brothers Columbus A. and Carolus J., in spite of their Northern birth, all joined the Confederate Army. Kelion became a sergeant in Quirk’s Scouts of John Hunt Morgan’s cavalry, and Carolus served in Ben Hardin Helm’s 1st Kentucky Cavalry, CSA, and then in Quirk’s Scouts. Kelion was captured July 19, 1863 at Buffington Island, Ohio, while on Morgan’s “Great Raid” and spent the rest of the war as a prisoner of war. Carolus was captured near Gallatin, Tennessee, and reputedly was held captive a couple of months before he

was escorted away and shot. After the war, in 1867, Kelion moved to Palmyra, Missouri, where he followed several occupations in succession.⁹

The only 1861 date located in Hundred Dome Cave is beside “T. Toney.” It is not known if he was a civilian or a soldier at the time. However, he almost certainly was Thomas Toney (1842-1911), a son of Jesse and Mary (Elliott) Toney and in 1860 a student in Bowling Green. During the war he was a 2nd lieutenant in the 2nd Kentucky Cavalry, CSA. Later he became a doctor and dies at his home, 302 Main Street, Joplin, Missouri, of a spinal injury.¹⁰

In early 1862 the Confederate positions in Kentucky began to give way. First, Brigadier General Gorge H. Thomas thrashed the rebels under Felix K. Zollicoffer at Mill Springs south of Somerset in the southeastern part of the state. Second, Ulysses S. Grant’s army advanced through western Kentucky and captured Forts Henry and Donelson on the Tennessee and Cumberland Rivers in Tennessee. The Fall of Fort Henry alone caused Johnston to evacuate Bowling Green between February 8 and 14, after which the Army of the Ohio moved south to capture Nashville, generally following the Louisville and Nashville Railroad.¹¹

As the Union Army moved forward, its soldiers were aware that they were traversing a cavernous terrain. Consequently, when an opportunity arose, many of the men visited caves in the region. Mammoth Cave was already world famous with a substantial literature, including Charles W. Wright’s 1858 guide. Possibly due to the many Louisville newspaper reports from 1859 to 1861, which were often reprinted throughout the country, numbers of soldiers may have already known of other caves such

as Diamond, Osceola (Indian), and Hundred Domes.¹²

A graffiti search of Hundred Dome Cave on September 5, 2015 yielded the following names, initials, and fragments:

J G Nickols Feb 18th 1862
W L Lamborn 79th P. V.
Lieut J Fults 6th Regt W[?]
W[?] H_____ Soldier 1862
H. P. Schuyler 1 Wis Regt
W B McCu? 78 PA VOLS
A__a Morney[?] 79 Pa _Vol
A Dyer 1st Wis. V
B Clark 1862
W W Hamilton 78 1862 Co. D
W. W. H. 78 Regt PV
H T W 1862[?]
Lieut. Will. H. Smock 6th Regt W[?]
A B Bonna__[?] 1[?]8th Reg
J. H. Fridy Lancaster Co Pa 79th Regt
PV¹³

The fellows from this group which have been identified were all members of the Second Division under Brigadier Alexander Mcd. McCook. The 6th Indiana was in Brigadier General Lovell H. Rousseau’s Fourth Brigade, and the 78th and 79 Pennsylvania and 1st Wisconsin were in Brigadier General James S. Negley’s Seventh Brigade. On February 16 and 17, 1862, portions of the division marched south from Munfordville to camp not far below the ruins of Bell’s Tavern at present day Park City. Men of the Seventh Brigade congregated at what they called Camp Hambright near what they termed “Dripping Cave” which was used for a water sources. The namesake of the camp was Henry A. Hambright (1819-1893), colonel of the

79th Pennsylvania. The Fourth Brigade presumably was nearby. McCook's soldiers remained in this area until the 23rd. During that time a number of them broke their routine by checking out the natural attributes of "Dripping," Hundred Dome, and other caves.¹⁴

"N. J.," possibly of the 78th Pennsylvania, in a March 16 letter to a friend in his home state, described his trek through Hundred Dome Cave:

*The first room of the cave is fitted up for a ball room. It is floored and has closets, and staging for the band, and all complete.... The long avenues, the spacious rooms, the deep chasms, the high domes, the huge columns, the formations which encrust the rocks, the myriads of dormant bats which hang in ponderous (and almost numberless) be vies from the ceiling, all presented to me a new and interesting scene. We had no guide, and no light only that which our paraffine [sic] candles produced. We clambered down ladders and stair-ways, across bridges and around ledges, sometimes walking and sometimes crawling. We could not see the bottom of many of the chasms by the dim light of our candles, neither could we see the ceiling of some of the highest domes. We continued our explorations until our curiosity was entirely satisfied, and then returned to camp with a number of specimens...*¹⁵

On February 24, the 57th Indiana Infantry of Colonel Henry M. Carr's Twenty-first Brigade and Brigadier General Thomas J. Wood's Sixth Division left Munfordville

and marched south to Cave City. The next day they continued along the railroad "as far as Bell's tavern" where they camped until noon, February 26, waiting for their wagons to catch up. This delay "was improved by the men in visiting the numerous caves with which the country abounds. One very large one, not more than a mile from our camp, called Hundred Domes Cave, was visited by nearly all the men of the regiment."¹⁶

Nine of the soldiers whose names have been found in Hundred Dome Cave have been identified. Two, A. B. Bonnaffon and W. H. Smock are not certain. The others are. Their biographies follow:

Augustus Benton Bonaffon (1837-July 12, 1867), of French heritage and son of Anthony and Margaret Hasting Bonaffon, was a railroad freight agent and steamboat clerk before the war. He served as sergeant, Company K, 12th Pennsylvania (three months) Infantry, April 25-August 5, 1861. The following September 17 he became major of the 78th Pennsylvania Infantry. Subsequently, July 24, 1864, and March 11, 1865, he was advanced to lieutenant colonel and colonel of the regiment, mustering out December 14, 1865. He joined the regular army as 1st lieutenant in the 35th U. S. Infantry and died from yellow fever in Indianola, Texas.¹⁷

Albert Myron Dyer (April 11, 1840-May 9, 1910), a son of Charles and Anna Wood Dyer, was born in Bennington County, Vermont. By the late 1850s his family moved to Kenosha County, Wisconsin, where in 1860 he lived with a family named Smith. When the war began he served as 1st sergeant in Company G (Park City Grays), 1st Wisconsin (three months) Infantry, April 17-August 21, 1861, and then in Company C of that regiment's three years' organization, September 23, 1861-October 13, 1864, rising

from sergeant to 1st lieutenant, February 17, 1864. Sometime before 1870 he moved to Onondaga, New York, where he was a farm laborer. He remained in that area and is buried in Oakwood Cemetery, Syracuse.¹⁸

Joseph Halls Fridy (January 3, 1836-March 4, 1900), a son of Joseph and Elizabeth Fridy, was a carpenter and resident of West Hempfield Township, Lancaster County, Pennsylvania. He mustered in as a private in Company E, 79th Pennsylvania Infantry September 20, 1861, was promoted to quartermaster sergeant February 10, 1864, and served until the regiment was discharged, July 12, 1865. Probably sometime later, he married a woman named Annie (1838-1909). In 1889 he was a deputy IRS collector in Lancaster County. He and his wife are buried in Mountville Cemetery in his home county.¹⁹

Josiah Fults (c1838-c1870-74), an Ohio native and Bartholomew County, Indiana, harness maker, married Mary E. Brown in December 1858. Between 1859 and 1866 they had three sons and one daughter. On September 20, 1861 he was commissioned 2nd lieutenant in Company G, 6th Indiana Infantry, but six months later, about March 29, 1862, he resigned. The following year he was a retail liquor dealer, and on May 20 1868, he was appointed postmaster of Elizabethtown. Two years later, still in Bartholomew County, he was listed as a druggist possessing a total estate worth \$5,000. Soon thereafter he apparently died, and Mary B. Fults married a second time on March 15, 1874, to T. C. Ireland. About 1886 they moved to Ringgold County, Iowa, where one of her sons, Romney C. Fults, also lived.²⁰

William Wallace Hamilton (September 23, 1835-November 7, 1891) was a son of Robert A. and Anna Mary Evers Hamilton

and was born at Hollidaysburg, Blair County, Pennsylvania. In 1848 his family moved a few dozen miles northwest to Montgomery Township, Indiana County. William grew up on a farm and usually pursued that occupation plus lumbering. On September 1, 1861, he joined Company D, 78th Pennsylvania Infantry, and weeks later, October 12, was promoted to sergeant. He also played the fife, and on January 14, 1863, was discharged at Nashville on a surgeon's certificate of disability. The next summer, July 6-August 18, under a call by the governor occasioned by the Confederate invasion of the state, he served as a 2nd lieutenant in the 46th Pennsylvania Volunteer Militia. On November 29, 1864, Hamilton married Susan Clark and they had at least three sons and one daughter. Briefly, 1865-67, he operated a store in Cherry Tree, also in Indiana County.²¹

William Lewis Lamborn (January 6, 1839-July 4/5, 1875), a son of Smedley and Margaret Bolton Lamborn, was born in Lancaster County, Pennsylvania, and was educated at the State Normal School at Millersburg (now Millersville). For a while during the late 1850s he was a teacher. On September 23, 1861, he joined Company E, 79th Pennsylvania Infantry as a private, serving until March, 1863, when he was discharged for disability. Early in 1864 he married Phebe M. Barnard (1837-1874) and after her death, Emily Corbin (1845-1880). He had a variety of jobs and residences after leaving the army: Drumore Township, Lancaster County, 1863-66 and later; Currituck County, North Carolina. 1866-69, where he grew peaches, Kent County, Maryland, 1869; Philadelphia, 1870, where he sold fertilizer; Riverton, New Jersey; and Steelton, Pennsylvania. At the last place he invented a railroad frog and a railroad indicator (a machine to note the time a train

passed a station). In 1874 he partnered with George Bent at Harrisburg to manufacture his inventions, and he traveled widely to promote them. He died at Goshen in his home county and is buried in Drumore Cemetery.²²

William B. McCue (June, 1839-March 31, 1867) of Armstrong County, Pennsylvania, was a son of John and Eleanor Hoover McCue. By 1860 he was married and working as an oil refiner. In September the next year he joined the 78th Pennsylvania Infantry, Company F, and was eventually commissioned 1st lieutenant. At Nashville on November 29, 1862, he resigned. Later, February 29, 1864, he enlisted in Company A of the same unit as sergeant, was once again promoted to 1st lieutenant the following December 2, and two days after that became the regimental quartermaster, serving until September 11, 1865. He returned home, presumably Freeport, and at some point fathered a son, Joseph Benton McCue. He is buried near his parents in Freeport Cemetery.²³

Herman P. Schuyler (September 1842-August 4, 1909), a native of Albany County, New York, and a direct descendent of Revolutionary War General Philip Schuyler, was a resident of West Troy, New York. After the war began for some reason he traveled west and enlisted in Company A, 1st Wisconsin Infantry September 26, 1861. From sergeant he was promoted sergeant major, October 29, 1862, and 2nd lieutenant, January 26, 1863, and 1st lieutenant, February 3, 1863, resigning April 12, 1864. Soon thereafter and until 1870 he worked with army ordnance at Watervliet Arsenal, New York. Subsequent to that he was head of sales at Troy Steel and Iron Company; private secretary of a Standard Oil Company official in New York City, 1887-90; head of sales at Wellman Steel and Iron Company

at Thurlow, Pennsylvania, 1890-93; and from then until his death he was assistant treasurer of the General Electric Company at Schenectady. His final home was in Albany and he is buried in Albany Rural Cemetery. His wife was much younger and they had a son and daughter.²⁴

William H. Smock is one of at least three men with that name in mid-nineteenth century Indiana. Probably the one who toured the cave was the locally born day laborer (c1838-c1880-83) who before the war lived in Hanover in Jefferson County with his parents John and Elizabeth Smock, both Kentuckians. He served as a corporal April 22-August 2, 1861 in the three month organization of the 6th Indiana Infantry before obtaining a commission as 1st lieutenant in Company K of that regiment's three year service. He did duty as such from September 20, 1861, until March 28, 1862, when he resigned. Sometime later he married a girl named Nannie J. and by 1866 they had a son, Harry E. They lived in Ward 6 of Indianapolis in 1870 where he was a pump maker. Ten years hence they lived in Johnson County Indiana, where he was a farmer. In that year's census his parents' place of birth were both given as Kentucky, seeming to verify that he is the same man shown in 1860 Jefferson County. He died soon after, and in 1883 his widow and son were again living in Indianapolis, at 164 W. Maryland Street.²⁵

These soldiers are a fairly typical representation of the lives of mid-nineteenth century men of the northern United States. Their life spans ranged from twenty-eight to seventy, with the average around forty-eight. Four went back home and stayed there. The others moved about, sometimes frequently, and pursued a variety of jobs. Although two briefly held positions with the Federal government, H. P. Schuyler, who became

an official at General Electric, became the most prominent. But none of that mattered in early 1862, when for a few hours they sought a distraction from the hardships of military campaigning by visiting Hundred Dome Cave.

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Footnotes

1. *Lexington Reporter*, March 30, 1813; Joyce M. Murray, *Deed Abstracts of Warren County, Kentucky 1797-1812* (Dallas, Texas, 1985, 21, 23, 28, 29, 38, 63, 71, 73, 88, 103; “Hubbard and Gatewood Families,” annefield.net; Angelo I. George, *Mammoth Cave Saltpeter Works* (Louisville, 2005), 74.

2. G. S. Bailey, *The Great Caverns of Kentucky* (Chicago, 1863), 40; Sandi Gorin, “The Winn Family,” South-Central-Kentucky-Archives, rootsweb.ancestry.com; 1860 Census, Ky., Edmonson, Brownsville P. O., 81; Franklin Gorin, *The Times of Long Ago: Barren County Kentucky* (Louisville, 1929), 18; India W. P. Logan, *Kelion Franklin Peddicord of Quirk’s Scouts Morgan’s Kentucky Cavalry, C. S. A.* (New York and Washington D.C., 1908), 10-12, 21-27.

3. *Ibid.*, 27; Bailey, *Great Caverns of Kentucky*, 39; *Marshall County Republican*, January 28, 1860; Diary of Marion O. Smith, September 5, 2015; Unpublished photograph by Charles S. Bishop of Lexington, Kentucky.

4. Diary of Marion O. Smith, September 5, 2015; Charles Kerr, ed., *History of Kentucky* (5 vols., New York and Chicago, 1922), 5: 347; Sam McDowell, *Society of Kentucky Pioneers 1983 Yearbook* (n.p.,

1985), 94; RootsWeb.com (South-Central-Kentucky-Archives); C. E. Coode and W. L. Gardner, Jr., eds., *Barren County Heritage: A Pictorial History of Barren County, Kentucky* (Bowling Green, 1980), 72, 273; FindaGrave.com; 1850 Census, Ky., Christian, Dist. No. 1, 875; (1870), McCracken, Precinct No. 3, 12.

5. Bailey, *Great Caverns of Kentucky*, 40; *Louisville Daily Journal*, March 24, 1860; Diary of Marion O. Smith, September 5, 2015; 1870 Census, Ky., Warren, Bowling Green, 89; FindaGrave.com.

6. *Louisville Journal*, March 24, 1860; Bailey, *Great Caverns of Kentucky*.

7. Diary of Marion O. Smith, September 5, 2015; 1860 Census, Ky., Muhlenberg, Dist. No. 1, 875, Greenville, P. O. 17; (1870), Nelson, Bardstown, 18.

8. Stanley F. Horn, *The Army of Tennessee* (Norman, Okla., 1941), 44-67; Gerald J. Prokopowicz, *All for the Regiment: The Army of the Ohio, 1861-1862* (Chapel Hill and London, 2001), 12-17, 35; Dan Lee, *The L & N Railroad in the Civil War* (Jefferson, N. C. and London, 2011), 25-52; *Official Records*, Ser. 1, Vols. 4 and 7.

9. Logan, *Kelion Franklin Peddicord*, 12-13, 17-18, 31-32, 146-49, 161-162.

10. 1860 Census, Ky., Warren, Dist. No. 1, Bowling Green P. O., 10; *Report of the Adjutant General of the State. Confederate Kentucky Volunteers* (Hartford, Ky., 1979 [1902]), 590; FindaGrave.com.

11. *Official Records*, Ser. 1, Vol. 7; Lee, *L & N Railroad*, 53-57.

12. Charles W. Wright, *Mammoth Cave, Kentucky* (Vincennes, Ind., 1858); *Louisville Daily Journal*, October 5 and December 1, 1859, March 24, April 21, October 18, 1860,

July 25, 26, August 1, 1861; *Louisville Daily Democrat*, May 15, 1860, August 11, 1861; *Louisville Daily Courier*, August 2, 19, 26, 1859, May 14, September 1, 1860; *Louisville Weekly Courier*, September 3, 1859; *New York Spirit of the Times*, September 8, 1860; Washington (D.C.) *National Republican*, August 3, 1861; *Dayton Daily Empire*, May 5, 1860; *Holmes County (Mich.) Republican*, May 10, 1860.

13. Diary of Marion O. Smith, September 5, 2015.

14. *Official Records*, Ser. 1, Vol. 7; Joseph T. Gibson, ed., *History of the Seventy-Eighth Pennsylvania Volunteer Infantry* (Pittsburgh, Pa., 1905), 35; Ebensburg (Pa.) *The Alleghanian*, March 13, April 3, 1862; Clearfield (Pa.) *Raftsmen's Journal*, March 19, 1862; Roger D. Hunt and Jack R. Brown, *Brevet Generals in Blue* (Gaithersburg, Md., 1990), 256.

15. Clearfield (Pa.) *Raftsmen's Journal*, March 19, 1862.

16. *Official Records*, Ser. 1, Vol. 7; Asbury L. Kerwood, *Annals of the Fifty-Seventh Regiment Indiana Volunteers* (Dayton, Ohio, 1868), 38-39.

17. Roger D. Hunt, *Colonels in Blue...The Mid-Atlantic States* (Mechanicsburg, Pa., 2007), 36-37; FindaGrave.com.

18. *1850 Census*, Vt., Bennington, Shaftsbury; (1860), Wis., Kenosha, Salem, 174; (1870) New York, Onondaga, Onondaga, 548B; *The History of Racine and Kenosha Counties, Wisconsin* (Chicago, 1879), 559; *Roster of Wisconsin Volunteers* (2 vols., Madison, Wis., 1886), 1: 319; FindaGrave.com.

19. Samuel P. Bates, *History of Pennsylvania Volunteers*, 1861-5 (5 vols., Harrisburg, Pa., 1869-71), 4:1084, 1096-97; Consolidated List

of Civil War Draft Registration Records, RG110, National Archives; *Official Register of the United States (1889)*, 132; Lancaster County (Pa.) Register of Wills; FindaGrave.com.

20. *1860 Census*, Ind., Bartholomew, Newbern Clifty Twp., 89; (1870), Taylorsville German Twp., 3; *Report of the Adjutant General of Indiana* (8 vols., 1865-69), 2: 351; Marriage Records, Bartholomew County, Indiana; U.S. IRS Tax Assessment Lists, 1862-1918; Mytree.com; FindaGrave.com.

21. T. J. Stewart, comp., *Indiana County, Indiana: Her People, Past and Present* (2 vols., Chicago, 1923), 2: 1224-5.

22. Bates, *History of Pennsylvania Volunteers*, 4: 1097; Samuel Lamborn, *The Genealogy of the Lamborn Family* (Philadelphia, 1894), 215-17; FindaGrave.com.

23. Gibson, *Seventy-Eighth Pennsylvania Infantry*, 18, 216; 63d Congress, 2d Session, Senate Documents (Washington D.C., 1914), Document No. 344; FindaGrave.com.

24. *Roster of Wisconsin Volunteers*, 1: 313; 1900 Census, New York, Schenectady, Schenectady, Ward 4, p. 6A; *Electrical World*, Vol. LIV (July 1-Dec. 3, 1909), 455; *Railroad Age Gazette* (1909 Second Half), August 27, 1909, p. 389; *New York Iron Age*, July 1, 1909; FindaGrave.com.

25. *1860 Census*, Ind., Jefferson, Hanover Twp., 50; (1870), Marion, Indianapolis, 6th Ward, 38; (1880), Johnson, Clark Twp., 149th Enum. Dist., 17; *Adjutant General of Indiana*, 2: 354, 4:3; *R. L. Polk & Co.'s Indianapolis Directory* (1883), 562.

Archeological Excavations in Advance of the Historic Tour Trail Rehabilitation

Steven R. Ahler¹ and Rebecca L. Hummel¹

¹ University of Kentucky

Introduction

Archaeological excavations were conducted by the University of Kentucky's Program for Archaeological Research in 2014 and 2015 in advance of rehabilitation of the Historic Tour Trail within Mammoth Cave. The purpose of the archaeological testing was to provide evaluations of the scientific significance and research potential of any archaeological deposits that will be impacted by the proposed trail rehabilitation. Mammoth Cave is an archaeological site (15ED1) that is listed on the National Register of Historic Places. Archaeological and paleontological testing conducted in 2003 (Trader, in progress) and 2008 (Ahler 2012) documented intact and scientifically significant prehistoric archaeological deposits. Because portions of the Historic Tour Trail are eligible for listing on the National Register of Historic Places, the National Park Service was required to evaluate the impact that trail rehabilitation activities will have on the archaeological deposits.

The 2008 excavations produced maps that provided general guidance to the Park Service regarding the potential for encountering either archaeological or paleontological deposits along the various tourism trails within the cave. However, only relatively gross categories of nil, low, medium, and high potential could be developed. Following up on this coarse-grained evaluation, the current project involved excavation of additional test units in segments of the Historic Tour Trail that had been evaluated as having medium or high potential for containing archaeological deposits. (There was no potential for intact paleontological deposits.)

Field and Laboratory Methods

UK-PAR followed field methods established through earlier archaeological excavations along the historic trails. All test units were 3-x-3 feet in area and were excavated in natural stratigraphic zones whenever possible. The first level removed the

sediment and rock fill that comprises the current trail (Stratum 1), constructed by the Civilian Conservation Corps in the mid-1930s. Subsequent levels removed either arbitrary or natural zones within underlying prehistoric deposits, designated as Stratum 2. Stratum 2 is composed largely of rock, with ashy sediment and artifacts filling interstices. Stratum 3 is basal cave sediment. Excavation units were confined to existing trails and to areas immediately adjacent to trails that might be disturbed during trail rehabilitation activities. Specific excavation unit placement was based on local conditions such as slope, width of the trail, evidence of previous disturbance, and thickness of the trail deposits.

All rock removed during excavation was examined for evidence of human modification. Soft sediment was screened in-cave through ½-inch mesh, and a 25% sample of the < ½-inch fraction from Stratum 2 was retained as a bulk sediment sample that was size-graded and analyzed in

the laboratory. When excavation was halted, unit walls were drawn at 1:12 scale and photographed. All units were backfilled to approximate original contour and conditions.

The primary goal of the artifact analyses has been to identify the range of prehistoric activities conducted at the investigated areas along the Historic Tour Trail. Nearly all activities required illumination, resulting in accumulation of abundant torch debris and torch ties. The most common activities conducted in the cave passages are apparently related to mineral mining, which took place mainly during the Early Woodland period, between about 2400 and 3000 years ago, based on previous radiocarbon assays. However, other artifact classes suggest additional activities were carried out in some locations, including cave exploration, storage of subsistence remains, processing of mined minerals, ritual activities related to ingestion of cathartic minerals (see Crothers 1997), and maintenance of staging areas (Ahler 2012). Laboratory analyses focused on 1) documentation of variation in the densities of prehistoric cultural material and 2) identification of artifacts indicative of

specific types of activities that took place in the cave, in addition to the commonplace activity of illumination.

Results of Field Investigations and Laboratory Work (Ongoing)

A total of 20 test units were excavated in five investigation areas along the Historic Tour Trail. A single unit in Vanderbilt Hall produced few prehistoric remains, but a probable 19th century flagstone trail was documented. A unit at Darnells Way near Washington Pit was minimally productive, though cane charcoal suggests that this area was explored prehistorically. A unit placed at the transition from Giants Coffin to the Acute Angle also revealed a portion of an earlier historic trail, along with low numbers of prehistoric artifacts. Eight units were excavated in the Audubon Avenue segment (Figure 1), and nine units comprising a single continuous block were excavated at Giants Coffin (Figure 2). A total of about 367 cubic feet of sediment (10.4 m³) was excavated. The following discussion focuses on results from Audubon Avenue and Giants Coffin areas, which were the most informative.

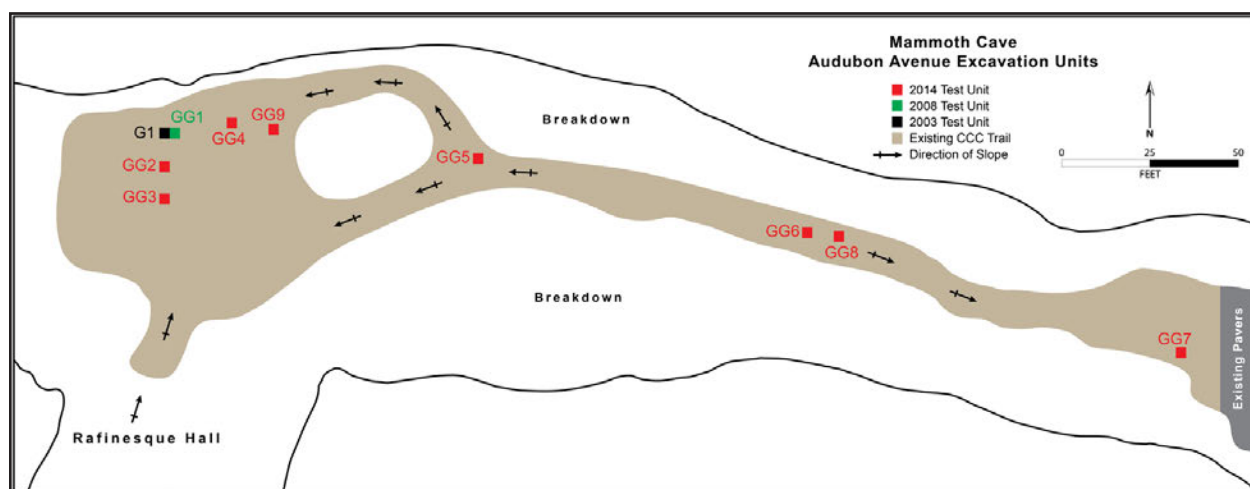


Figure 1: General plan of Audubon Avenue showing 2003, 2008, and 2014 Unit Locations.

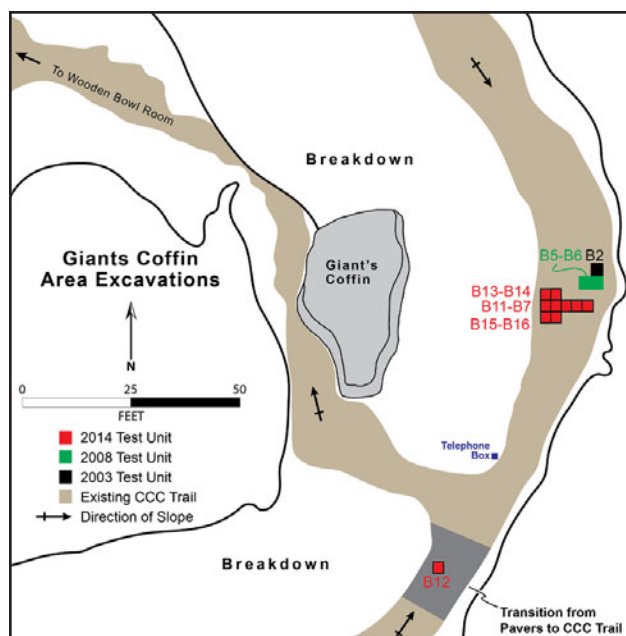


Figure 2: General Plan of Giants Coffin Area showing 2003, 2008, and 2014 Unit Locations.

In all excavation units, the most common cultural materials encountered in Stratum 1 were historic artifacts such as match sticks and paper, but prehistoric materials were often mixed with the trail fill. Prehistoric botanical remains were by far the most common materials in Stratum 2, though some historic artifacts were present, even in the lowest excavation levels. Historic materials sift down into the stratigraphic column because there are many voids in the rocky fill of Stratum 2.

Audubon Avenue Units

Eight units were placed along the Audubon Avenue section of trail that extends about 380 feet west of the end of the current pavers (Figure 1). Continuing west from the present terminus of the pavers, the CCC trail is relatively wide and flat, then narrows and slopes upward between large rocks to a long crest, then slopes downward to a broad (north-south) area at Rafinesque Hall. Earlier excavations in Audubon Avenue included

Units G1 and G2 in 2003 and Unit GG1 in 2008 (Ahler 2012). Both G1 and GG1 were placed about 5 feet south of the north cave wall near the west end of Audubon Avenue (Figure 1). Unit G1 had produced a moderate amount of carbonized and uncarbonized remains, mainly torch debris that was highly fragmented. A sample of wood charcoal and nutshell fragments below a large boulder was radiocarbon dated to 4170 ± 70 BP (Beta-183329), which is one of the earliest dates from the dark zone of Mammoth Cave (Trader, in progress). Testing conducted in 2008 in the adjacent Unit GG1 produced subsistence remains and gourd fragments. Audubon Avenue in general was considered to have moderate archaeological potential (Ahler 2012).

The 2014 Audubon Avenue units (GG2 through GG9) all showed the expected stratigraphic sequence of Stratum 1 CCC trail fill overlying Stratum 2 containing rocks mixed with prehistoric anthropogenic ashy sediment. However, the thickness of Strata 1 and 2 varied considerably among units, as did the amount of prehistoric cultural material recovered.

Units GG2 and GG3 were placed south of GG1 to provide data for a north-south cross-section of west end of the trail area. These units showed increasingly deep Stratum 1B deposits to the south, indicating that the west end of Audubon had been a broad depression that was now filled with historic trail deposits. Units GG4, GG5, GG6, and GG7 were spaced along the trail, and Units GG8 and GG9 were placed near units that had higher artifact density. These units documented high variability in artifact density.

Figure 3 shows the density of selected material classes for various excavation units. The Audubon Avenue units (GG2 through

GG9) have low densities of cane torch debris (measured in grams/excavated liter), indicating relatively low-intensity prehistoric usage of this part of the cave (Figure 3a). However, raw numbers of recovered cane torch debris are highly variable, ranging from zero in Unit GG3 to more than 300 fragments in both Unit GG6 and GG8. Units GG4 and GG9, close together in the western part of Audubon Avenue, produced moderate amounts of cane. The density of torch ties/cordage (number per liter of bulk sediment) as expected mirrors the density of cane. The density of seeds (number per liter of bulk sediment) is a possible indicator of food consumption or storage. These density data (Figure 3b) show the highest densities in Units GG6, GG8, and GG9, which suggests that prehistoric activities in Audubon Avenue included food consumption or storage in the same general locations where illumination was required. Mineral mining is one of the prehistoric activities that has been documented within Mammoth Cave, and the density of gypsum/selenium crystals (measured in grams/liter of bulk sediment) recovered from the ¼-inch to ½-inch size grade was calculated as an index of this activity. These data (Figure 3c) show that in contrast to the high cane and seed densities, Units GG6 and GG8 produced no mineral fragments. Instead, Unit GG9 had high mineral density, followed by Unit GG7, which had very low densities of cane and seeds.

These artifact density data show three overall patterns for the Audubon Avenue segment of the Historic Tour Trail. First, the original characterization of Audubon Avenue as an area of moderate potential for prehistoric remains is generally supported, but might be refined as having

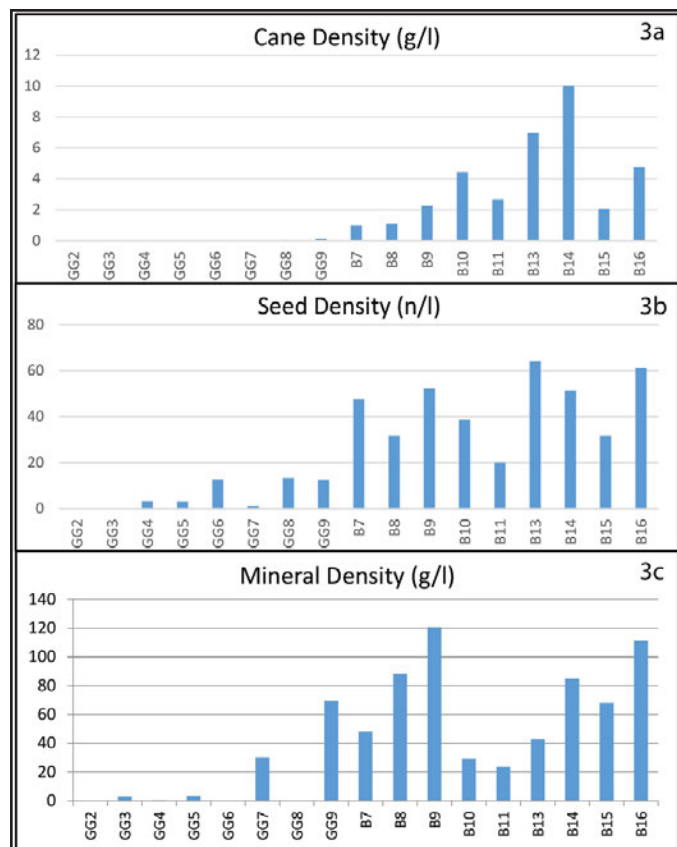


Figure 3: Densities of Selected Material Classes from 2014-2015 Excavations at Audubon Avenue and Giants Coffin.

low-to-moderate potential. Second, artifact density is highly variable along the trail, which is typical of cave and rock shelter deposits. Activity areas and preservation environments change rapidly depending on local conditions. Third, the types of artifacts recovered indicate that the major prehistoric activities in this part of the cave were mineral mining and possibly food storage/consumption. However, these activities did not necessarily take place in the same locations along the trail.

Giants Coffin Units

Nine units were placed in the Giants Coffin area (Figure 2). Units B7 through B11 comprise an east-west trench that spans nearly the entire width of the existing trail.

After these units were completed, the west end of this trench was expanded into an excavation block of six contiguous units with the addition of B13 and B14 north of the trench and B15 and B16 south of the trench. The trench location was selected based on previous work in Giants Coffin. Unit B2 was excavated in 2003, and it produced abundant cultural material, including the only complete sunflower head recovered from Mammoth Cave. In 2008, Units B5 and B6 produced an additional fragmented sunflower head. The trench was placed three feet south of Units B5-B6 to further sample this area. Depth of deposits ranged from 2.5 to 3.5 feet and it became clear during excavation that the lower portion of the Stratum 2 deposits was producing a high proportion of the cultural material. Stratum 2 was subdivided into upper, middle, and lower levels, and eventually the lower portion with its higher amounts of material was designated Stratum 2C.

Cultural material was highly abundant in all of the Giants Coffin units. The density data in Figure 3 is based on material recovered from the lower portions of Stratum 2, which included the least amount of historic contaminants. Figure 3a shows that cane densities are generally between one and two orders of magnitude higher than the Audubon Avenue units (GG series). These data also show a generally increasing trend of cane density from east to west across the trench, decreasing slightly at the far west end (Unit B11). Cordage density mirrors the cane density in general. Density of gypsum in the 1/4- to 1/2-inch size grade (Figure 3c) is more variable, but in general the values are consistently higher than for the Audubon Avenue units. This pattern indicates that this area was consistently used for gypsum crystal extraction. The density of seeds is consistently higher than

any of the Audubon Avenue units (Figure 3b), with density ranging from 1.5 to 5 times as high in the Giants Coffin units. This finding indicates that Giants Coffin was consistently a location where food consumption or storage took place. The seed identification is still under way, but there are abundant examples of sunflower in Units B7 and B8, as was expected based on proximity to units that produced sunflower heads. In addition, there are high numbers of marsh elder and chenopodium, which are two other native plant domesticates, and high numbers of wild plant foods such as blackberry/raspberry and thin-shelled hickory. In addition to seeds from these food sources, many examples of the stem and flower heads of false foxglove (*Agalinis purpurea*, formerly *Gerardia purpurea*) were recovered in the Giants Coffin units. False foxglove stems may have been used as torch material, and it is likely that the stem was stripped longitudinally to make simple cordage for torch ties. False foxglove was not recovered in any substantial quantities from any of the Audubon Avenue units. Recovery of high densities of this plant suggests that the Giants Coffin area may have been a location where torches were prepared and tied, and where torch tie raw materials may have been stored for future use.

Other indicators of the types of activities conducted in the Giants Coffin area are derived from specific artifact classes that were recovered here and which are either very rare or absent from other investigated areas within the cave (Table 1). Presence of human paleofeces is perhaps an index of the intensity of prehistoric use in this part of the cave. In addition, human paleofeces suggest that the function of the Giants Coffin area may have changed through time. It might not be considered acceptable behavior to defecate near an area that was

actively occupied or visited, but it might be acceptable in an area had been abandoned and was no longer actively used. Of considerable interest is the recovery of chert debitage from Units B10 and B14, which are adjacent to each other (see Figure 2). Chert artifacts are extremely rare in the dark zone of Mammoth Cave, and excavation of 44 test units in 2008 produced no chert artifacts. Their presence in the Giants Coffin area indicates that other activities were taking place, possibly use of chert artifacts to manufacture or modify other materials, such as torches and torch ties. Use-wear analysis of the chert may help to identify specific tool functions, but this has not yet been accomplished. Gourd and mussel shell were both recovered in small quantities, and only from the Giants Coffin units. Gourds were probably used as storage containers, and mussel shell may have been used to collect minerals, especially soluble minerals such as epsomite and mirabilite. These classes of remains suggest that collection and processing of minerals may have been another activity conducted in Giants Coffin but not in most other portions of the cave.

Unit	Human Paleofeces	Gourd Fragments	Shell Fragments	Lithics
GG4		1 (0.07 g)		
B7	9 (78 g)			
B8	2 (48.34 g)			
B9	2 (40.89 g)	2 (0.45 g)		
B10	6 (65.1 g)	3 (2.98 g)		2 (42.77 g)
B11	13 (5.42 g)	3 (1.18 g)	1 (0.93 g)	
B13		3 (1.5 g)	1 (1.9 g)	
B14				1 (25.8 g)
B15				
B16		1 (<0.1 g)		

Table 1: Locations of Recovery of Selected Artifact Classes from 2014-2015 Excavations at Audubon Avenue (GG4) and Giants Coffin (B series).

One of the most informative aspects of the excavation was the opportunity to expose a contiguous 6-x-9-foot block in the west end of the excavation area (see Figure 2). Figure 4 shows a composite drawing of the remains encountered just above basal cave deposits in this excavation block. A sample of powdery sediment was recovered from the deeply concave surface of the large rock in Unit B11. This sediment had a different texture than the general ashy Stratum 2 deposits and was confined to the concave surface. A portion of this sample was sent to the Kentucky Geological Survey for X-ray diffraction analysis. That technique identified a suite of minerals, including gypsum (calcium sulfate) in appreciable quantities. Presence of gypsum in the sample provides support for our in-field speculation that this concave rock surface had been used for processing and grinding of gypsum crystals collected from the cave walls. Gypsum processing was also apparently an activity that was conducted in this part of the cave. Additional quantitative analyses of samples are planned but have not been completed. Three rocks that were observed and mapped at this excavation level had polished upper surfaces.

All of these rocks were loose and all were found on top of a thin but dense deposit of cane and charcoal. These polished rocks suggest that the location was an area of repeated prehistoric activities, or perhaps part of a prehistoric trail, with use of the area frequent enough to modify the rock surfaces. A small patch on an adjacent large breakdown rock is also polished, possibly from sitting while conducting other activities.

These excavations clearly demonstrate that the Giants Coffin area is qualitatively different from

other portions of Mammoth Cave. Gypsum mining took place, which also has been documented in many locations throughout the upper-level passages. Other activities inferred from the artifacts recovered include grinding/processing of gypsum, storage or consumption of food, and manufacture or storage of torches. These latter activities suggest that the Giants Coffin was probably a staging area for exploration or mining activities that extended farther into the cave. This inference is supported by the fact that several large and small upper-level passages come together at or very near the Giants Coffin.

One of the results of the field work is that the University of Kentucky was able to provide more specific evaluations to the Park Service regarding the archaeological significance of the Giants Coffin. We found that this part of the cave was unique in the diversity and intensity of activities conducted, and

we recommended either additional major excavations or avoidance and preservation of this area. However, the Historic Tour Trail still needed rehabilitation, and the Park Service created a compromise by stipulating that the construction activities not impact the significant Stratum 2 deposits in this section of the trail, and that archaeological monitoring be conducted during construction work.

References Cited

- Ahler, Steven R. (editor). 2012. *Archaeological and Paleontological Investigations of Selected Trail Segments in Mammoth Cave and Great Onyx Cave, Edmonson County, Kentucky*. University of Kentucky Program for Archaeological Research Technical Report No. 714. Lexington.
- Crothers, George M. 1997. Preliminary Report on Archaeological Excavations in the Historic Section of Mammoth Cave: Houchins' Narrows, The Rotunda, and Broadway. Mammoth Cave National Park. Report submitted to the National Park Service, Mammoth Cave National Park.
- Trader, Patrick. In progress. *Phase II Archaeological Testing and Evaluation to Resolve OSHA Citation, Resource Deterioration, Cave Lighting System, and Trail Improvement, Mammoth Cave National Park Edmonson County, Kentucky*. University of Kentucky Program for Archaeological Research, Technical Report No. 501. Lexington.

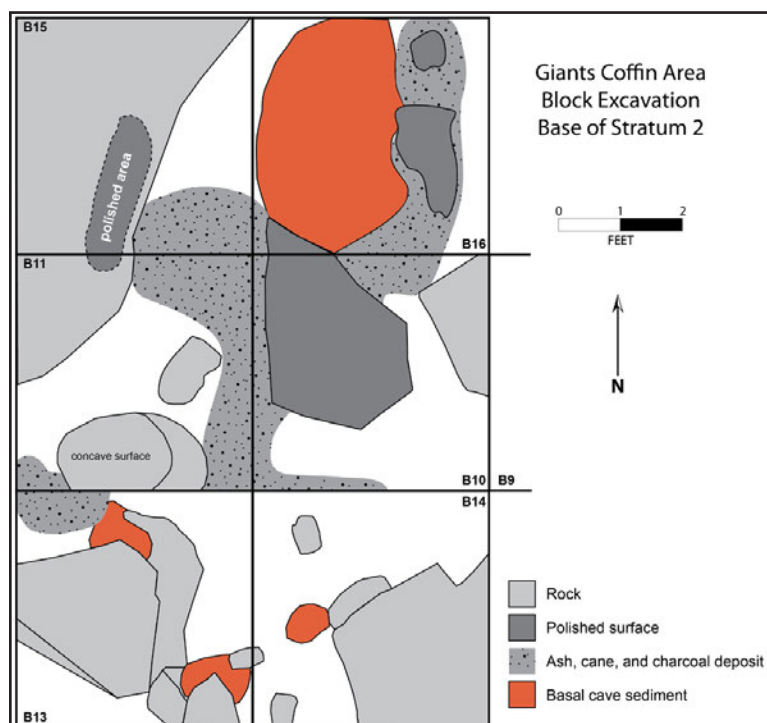


Figure 4: Plan view of 2015 Giants Coffin Excavation Block (Units B10, B11, B13-B16) at the Base of Stratum 2 Deposits.

Documentation and Conservation of the 1812-Era Saltpeter Works in Mammoth Cave, Kentucky

George M. Crothers¹ and Christina A. Pappas²

¹ William S. Webb Museum of Anthropology, University of Kentucky

² Office of State Archaeology, University of Kentucky

Abstract

Approximately 500 objects and features relating to the saltpeter mining operation at Mammoth Cave have been identified in the cave. Many of these objects remain in their original location as first constructed and are historical features in the cave. This includes many of the saltpeter vats, portions of the pump tower and pipeline, and the extensive oxcart trail. However, many portions of the saltpeter works were disassembled, reused for other purposes in the cave, and then scattered about after use. In 2015, we undertook a comprehensive program to thoroughly clean and document all of the extant remains, treat those wooden remains that were not in an advanced state of deterioration with a preservative, and move the disassociated remains to designated areas within the cave where they can be monitored and are free of dripping water or other agents of deterioration. In total, 238 objects were carefully cleaned and documented, and 84 objects were treated with a borate mineral salt to kill any active fungi. Careful documentation has allowed us to virtually reconstruct those portions of the operation that have been disassembled, and, while many sections of the operation were dismantled, a significant portion of those remains are still in the cave. Engineering details suggest that the works were constructed in at least two separate events with major design changes and improved construction techniques differentiating the two building episodes.

New Discovery Cultural Artifact Inventory and Analysis Project Update

David Kime¹, Jillian Goins¹, Robert Jensen¹, Clayton Johnson¹, Alessa Rulli¹, and Victoria Voss¹

¹ Honors Program, Northern Kentucky University

Abstract

The New Discovery section of Mammoth Cave was discovered in 1939. The Civilian Conservation Corps (CCC) began building trails in preparation for tourists. In April of 1942, workers were reassigned to above ground projects and the CCC was disbanded later that year. The construction in New Discovery was never completed and the artifacts left in the passages remain in place today. An inventory of these artifacts contributes to a better understanding of underground CCC projects, and also helps assess the conditions of the artifacts. The findings of this inventory may lead to future work to preserve and interpret these artifacts.

Recent Investigations at 15Ed23: Historic and Cultural Resources in a Disturbed Cave Environment

Joseph C. Douglas¹, Alan Cressler², George M. Crothers³, Marion O. Smith, Kristen Bobo⁴, and Justin Carlson³

¹ Volunteer State Community College

² University of Tennessee C.A.R.T.

³ University of Kentucky

⁴ Tennessee Cave Survey

Introduction

In late 2015 and early 2016, the authors began to examine the historic and cultural resources of 15Ed23, a large cave in the Mammoth Cave area. The cave was mined for saltpeter and commercialized as a show cave, both of which greatly modified the cave's natural environment and disturbed the site's archaeological record. Despite this, our investigation shows significant resources surviving from the cave's rich past. This paper introduces the cave site and presents our preliminary assessment of its prehistoric and historic resources. The archaeological components include saltpeter mining artifacts and evidence of early social and recreational visitation, both from the Nineteenth Century. We also found that Native Americans used the deep cave environment for extractive, mortuary, and ceremonial purposes in the Early Woodland Period.

15Ed23 is a lengthy and complex three dimensional maze cave in Edmonson County, located on private property in the rolling knobs south of Mammoth Cave National Park. It is developed in the Mississippian-age Girkin Formation and underlying Ste. Genevieve limestone. The cave has had many names in the past, so for clarity (and security) we refer to it by its Kentucky site file number. There is little documentary record for the site prior to the mid-twentieth century, but in 1949 organized cavers started to intensively explore the cave. These expeditions began a series of long-term efforts by Kentucky, Ohio, and other cavers to fully explore and map the cave, which continue to the present. Cavers in the 1950s and 1960s made important discoveries in the cave, but many aspects of the site's history have remained little known until recently.¹

Saltpeter Mining

Previous research at the cave indicated that it was mined for saltpeter for the gunpowder trade in the early 1800s, probably during the War of 1812. At that time the price of saltpeter increased greatly and numerous caves in the region were mined for nitrates, including nearby Hundred Dome Cave, where a large saltpeter boiling furnace was in operation at the entrance in 1813. In the early 1960s, cavers working in the cave found and photographed a side-handled wooden saltpeter paddle.² Handmade mining tools, paddles were used to remove dirt from under rocks and ledges and are diagnostic for saltpeter mining. Early cavers also photographed evidence of sediment removal, possible tally marks on the walls, and other possible mining implements. In his 1985 booklet *Gunpowder at Mammoth Cave*, Duane De Paepe gives one sentence to the saltpeter mining at 15Ed23, noting

that “a wooden saltpeter paddle was found a few years back, but it is doubtful that much mining occurred because there was no reliable source of leach water.”³ We do not know if De Paepe actually visited the cave.

A year later, in November 1986, Angelo George led a group of researchers to 15Ed23 on a brief trip to “inspect the cave for saltpeter activity.” The party examined passages in two areas, the Left Hand Maze and the Right Hand Maze, and George later reported that they found mining evidence in both areas, including “mattock marks, tally marks, maxi tally marks, many lamp seats, and a number of gluts.” He also noted that the blasting, digging, and filling associated with the commercialization of the cave in the 1960s had altered a number of passages. Although he did not identify a processing area where leaching vats had been located, George suggested that a large pool of water in the Left Hand Maze may have been used for leaching sediments. He concluded by directly disagreeing with De Paepe, saying the cave “must have been a major saltpeter site.”⁴

Our initial assessment of cave passages, while limited to areas without roosting bats, found abundant evidence for saltpeter mining in much of the upper cave, including both major maze areas. Like George, we saw metal tool marks on walls and sediment banks, and carbon wall marks from the miners’ pine torches. We saw many tally marks but most are atypical. There is one series of 40 evenly spaced short lines in the left maze. Nearby there are c. 92 long to very long thick gouged lines on the upper wall. One section of these is particularly intriguing, c. 16 very long incised lines which appear to overlay a historic smoked graffito, but at the top there are several horizontal lines crossing the vertical ones, making a grid pattern.

We noted a number of additional saltpeter mining features; there are piles of waste rocks on ledges and along the sides of passages in several areas. There are also sediment lines on walls indicating previous levels of dirt fill. We did not identify a sediment leaching vat (or processing) area. However, in an extensive wood rat area in the Left Hand Maze there are numerous small pieces of dried, hand-hewn wood, which when found in saltpeter contexts are generally interpreted as the remains of the clapboard side slats of V-shaped leaching vats. We also examined a wooden artifact attributed to 15Ed23, a saltpeter mining paddle, in the owners’ personal collection. This handmade scraping tool has a center-handle and is clearly different from the side-handle paddle photographed by cavers around 1962. At least two paddles came from the site, although one of them is currently lost. Overall, our assessment supports George; while access to the sediments was not easy prior to passage enlargement for tourism, much dirt was excavated by saltpeter miners, and perhaps initially processed in the cave. Although many of the details of the operation are obscure, like exactly who worked the site, the cave was a sizable source of valuable nitrates early in the early 1800s.

Social and Recreational Visitation

15Ed23 has several historic wall markings in various media from the Nineteenth and early twentieth centuries representing social and recreation visitation to the cave, some of which we recorded. In the Right Hand Maze are two inscriptions “J.U.B. 1815” but their authenticity is uncertain. From the antebellum era there are two well-preserved names and dates smoked onto the ceiling of the Left Hand Maze, probably by candle, “A F Brown 1842” and “L.H. Davis 1842”. Unfortunately the common surnames Brown

and Davis make identification difficult. Nearby is an undated, smoked ceiling mark, “J. W. Satterfield”. This was probably J. W. Satterfield (Nov. 17, 1831-Dec. 12, 1915) from Caldwell County, who “has always been a farmer and a very successful one.” By 1885 he owned “about 900 acres of land, and an interest in two gristmills.” J.W. Satterfield married Miss L. M. Boyd on February 17, 1858, and ultimately they had 10 children, though only three survived in 1885. J. W. Satterfield’s inscribed name was also recorded in Hundred Dome Cave. J. W. and his wife are buried in the Cedar Hill Cemetery in Princeton, Kentucky.⁵

Another graffiti panel at 15Ed23, while representing recreational cave visitation, injects a Civil War context into the social history of the cave. On the wall is written, in a black applied substance (probably carbon), “J. L. N[e]wman” and centered underneath the name is “1862”. This was made by Joseph L. Newman, a private in Company H of the 58th Regiment Indiana Infantry. From Princeton, Indiana, and possibly of Native American origin, Newman was mustered into the Union Army on December 16, 1861. The 58th Indiana was encamped at Bardstown, Kentucky when Newman joined the unit. Receiving marching orders in mid-February 1862, the 58th Indiana moved south through Munfordville to Bowling Green and on to Nashville, where they had arrived by March 13. We know that many Union soldiers visited numerous caves in Kentucky during 1862, including a member of the 58th Indiana Infantry who visited Long Cave. Joseph Newman probably visited 15Ed23 during mid-late February 1862 while encamped near Glasgow Junction (Park City today). But his unit was also in Kentucky later in 1862 in response to Morgan’s Raid, so the cave visit could have occurred then. Poignantly, Newman died on January 2,

1863, less than a year after visiting 15Ed23, after suffering a thigh injury in the Battle of Stone River.⁶

Normally, Union soldiers visited caves in social groups rather than alone, so we looked closely for additional soldier names. We found several inscriptions with the name “W. W. Blair” but none have a date or indicate a soldier status. This could be Dr. William Wylie Blair (1827-1916), a Princeton, Indiana physician who was commissioned as Surgeon in the 58th Indiana Regiment Indiana Volunteers on October 19, 1861. He joined the Regiment on December 17, which he served until his resignation on March 25, 1864. He went on to a prominent medical career in Indiana. However, this identification is far from certain, as there are numerous Blairs in Kentucky and the cave inscriptions provide very limited information. There is additional historic graffiti present, as yet unidentified, such as “W. H. Galloway 18__[?]”. There is also graffiti from the last sixty years which remains unrecorded.⁷

Native American Usage

In the mid-1960s, the landowner at the time opened 15Ed23 to the public as a show cave, and it remained open until the mid-1980s. At the same time, cavers continued to explore and map the cave. Both the landowner and the cavers found significant evidence of pre-Columbian use of the cave. While not kept secret, the Native American components were not well-studied, with the result that the site has not been appreciated for its significance. Basic information such as exactly what was found, where, and by whom, was lost, or almost so. The early knowledge dropped through the cracks, so to speak. National Speleological Society members Charlie and Catherine Bishop introduced us to the mystery surrounding

the site in September 2015 by showing us a scrapbook with a 1962 caver photograph of cave art, a bird.⁸ One of the main goals of our subsequent field work was to relocate this art and document any other American Indian presence. We were able to relocate the bird glyph and other previously noted features. We also found much new material, and we have been able to establish a chronological context for the Pre-Columbian activities. 15Ed23 was used for mortuary, ceremonial and extractive purposes, in the Early Woodland Period, and it contains significant cultural materials.

In 1963, mortuary use of the cave was discovered when three associated individuals were found interred in a pit a short distance inside the dark zone; one adult and two juveniles. The bones were probably exposed during trail building for commercialization. The cave owner notified the University of Kentucky Anthropology Department and donated the burials along with two bags of material from the site, one labelled “Surface of Village” and the other “cave entrance.” No formal inventory or study of the material was made, although Lee Hanson of UK registered the cave as an archaeological site, and in April 1964 he sent a brief letter to the owner outlining “the facts concerning the skeleton” for the cave guides. Hanson noted that the adult burial was a woman in her twenties. She was wearing a bone bead necklace and a bone hairpin. Hanson apparently personally viewed the burial site, as he wrote that discolorations in the soil suggested that she was interred in clothes or wrapped in a robe. As for chronology, he suggested a possible Late Archaic date.⁹

A recent examination of the donated collection shows that it consists mostly of chert flakes and tool fragments, with a couple of stone pestles and one Early Archaic McCorkle-type point. We know

nothing about the supposed surface village, which may have been destroyed by subsequent road construction. Due to caver Charlie Bishop’s knowledge, we were able to examine the actual burial location in the cave, but the dirt has been almost completely removed; sediment lines on the walls indicate the previous floor level. Surprisingly, on the upper edge of the burial location, we found a perfect projectile point with considerable age, based on its patina. We identify it as part of the Barbed Cluster, probably most resembling a Buck Creek Barbed point (Figure 1). The Barbed Cluster points date from the Late Archaic through the Early Woodland, approximately 3500 to 2600 years ago.

Although almost unbelievable from today’s perspective, but in keeping with Kentucky’s competitive show cave history, in early 1964 the skeleton of the young Native American woman found in the cave was taken deeper into the cave, put inside a glass display case, and placed alongside the tourist trail. The guides nicknamed her Zelda, and she was one of the cave’s attractions for the next decade. Bizarre enough, but then in January



Figure 1: “Barbed Cluster” projectile point found near burials in 15Ed23.

1975, the skeleton was stolen from the cave. The owners at the time suspected it was probably a show cave competitor, and the macabre story made the newspapers.¹⁰ But as far as we know, the skeleton was never found. If ever located, we could reinter her in the cave where she belongs, as the cave site is now secured.

In March 1960, the owner of the cave showed visiting cavers “pick marks made by Indians mining salts”¹¹ not far inside the cave entrance. A scrapbook from the early 1960s has two photographs that show gypsum deposits, partially mined, with vertical digging stick marks on them. Our recent investigations confirm that Native Americans mined minerals in the cave, primarily gypsum but perhaps others as well. While subsequent saltpeter mining and tourist development have modified the cave floors so much that any evidence for crystal mining in sediments has been destroyed, there is ample evidence for removal of wall gypsum. There is a low section of wall in the Right Hand Maze, beyond a pit obstacle (now filled), with a 2 meter area of removed gypsum plate or crust. The presence of metal tool marks on top of the bash marks indicates that some mining was historic but there was also an earlier episode of mining. There are stoke marks on the walls from bundled cane torches in all of the mined areas.

There is a second extraction area, with intensive gypsum wall mining, in a complex of small passages, also in the Right Hand Maze. This section was never developed for tourism, although dirt was removed by saltpeter miners. There are bash marks on the gypsum deposits, which range up to 2 meters in height, and bare patches of wall where minerals were removed. There are burnt river cane fragments and carbonized wood or weed stalks from the Native

Americans’ lighting technology lying on areas of undisturbed substrate. There are no metal tool marks on the mined areas. There are sediment discolorations on some of the gypsum deposits, suggesting a higher dirt level at one time, and thus a complex history of sediment and gypsum removal. We did not find any obvious hammer-stones. We place 15Ed23 alongside Salts Cave and the many others in the Mammoth Cave region which were utilized by Native Americans as a source of culturally important minerals.

Like at 12th Unnamed Cave in Tennessee, early organized cavers working in 15Ed23 found and recorded an example of prehistoric cave art long before American archaeologists began to take the field of rock art, including cave art, seriously. In July of 1962, caver Craig Rodemaker photographed a large bird image in the Left Hand Maze. Although mistakenly called a pictograph on the caption (it is a petroglyph), the cavers thought it was probably a turkey, and that it might be significant. News of the find spread, but there were few people interested in eastern rock art, and those few who were did not have the opportunity to visit the site. Frank Fryman, Jr. of the University of Kentucky wrote to California rock art scholar Campbell Grant in early 1965 that “at Ed 23 a petroglyph drawing representing a turkey(?) was found on the ceiling of a passageway...”¹² This letter was passed to Dr. Fred E. Coy, Kentucky’s premier rock art scholar, but as he wrote in 1997, “I have never been able to find the Ed 23 site...”¹³ That same year, Coy wrote to other Kentucky archaeologists inquiring about the turkey glyph but no-one had seen the art or knew exactly where it was. As far as we know, Dr. Coy never visited the site, and again 15Ed23 dropped through the scholarly cracks. The turkey is not mentioned in any studies of Kentucky rock or cave art.¹⁴

On November 27, 2015, after intensive searching, we relocated the turkey petroglyph, glyph #1, on a ceiling in the Left Hand Maze, less than 10 meters from mortuary location (Figure 2). By we of course, I mean Kristen Bobo. The glyph is incised into the limestone bedrock and measures 40 cm long and 27 cm high. It is executed by a skilled and confident hand. It shows a turkey at rest, and the feet are not visible. The artist uses a fine line technique at the back of the body to suggest long feathers, and a pecking technique inside the body to show texture. The latter is a common pre-Columbian technique. While there are several birds in Kentucky rock art, there are few turkey petroglyphs, and while turkeys are a large component in southeastern cave art, the turkey at 15Ed23 is atypical. In many Tennessee cave turkeys, for instance, the bird is shown flying or walking, the wings are crosshatched, and the feet are an important design component. There appears to be nothing else quite like it known in Eastern America.

So far, we have found four additional petroglyphs in the same portion of the Left Hand Maze as the turkey. By we of course, I mean Kristen Bobo. Glyph #2 is an incised image measuring 30 cm long and 23 cm high located on the ceiling at a passage intersection. There is no cane charcoal

present here or around any of the art; the floor was removed by saltpeter miners. The image has a series of parallel lines at angles at the bottom with lines running at two angles superimposed on top. The edges on the upper right are indistinct. It could represent an irregular shaped object, perhaps woven, or it may be an abstract image. The use of crosshatching is common in cave art and in Kentucky its use extends back to the Late Archaic Period.

Glyph #3 is incised in the ceiling about 30 cm east of glyph #1 and measures 31 cm long and 3 cm wide (Figure 3). It consists of a long narrow D-shaped design, which is bisected by c. 12 more-or-less perpendicular lines. The patina of the drawing is old. That it lies under smoked historic graffiti (two letters) attests to its age. We identify this as a variant of the oval-shaped “toothy mouth” glyph, so called because it sometimes forms part of a human head effigy. The “toothy mouth” cave glyph is associated with multiple human burials in caves in eastern North America, and examples are known from multiple sites in Tennessee, and from Georgia and West Virginia. This is the first example identified in Kentucky. Chronologically, the motif is known from Archaic, Woodland, and Mississippian sites. Glyph #3 at 15Ed23 was probably created in the Early Woodland Period.¹⁵



Figure 2: Glyph #1 Turkey.



Figure 3: Glyph #3 “Toothy Mouth” motif.

Glyph #4 is a fine line incised petroglyph located on the ceiling 4.5 meters south of glyph #1 (Figure 4). It is a round spiral with six bands, measuring 27 cm in diameter. Spiral and concentric circle shapes are common in eastern rock art. Some of the authors think it might represent a snake, with a diamond head, forked tongue, and raised rattle, but others remain doubtful. Although it is impossible to directly date petroglyphs, it is almost certainly Native American in origin.

Glyph #5 was discovered in early 2016 in the same general area as the others. It consists of six or more long horizontal lines intersected by nineteen or more shorter vertical line, making a rectangular grid pattern. Faint lines near the grid complicate the panel and will require additional study. The patina is old. Grids are common in rock and cave art, including at Adair Glyph Cave in Kentucky. Regionally, grid patterned cave art is known from the Late Archaic through



Figure 4: Glyph #4 Spiral or Snake.

historic periods. Our initial assessment is that 15Ed23 is an important Kentucky cave art site.

As noted above, there is abundant evidence of American Indian exploration of 15Ed23 in the form of river cane torch marks, cane charcoal deposits, and other material from their lighting technology, especially in the Right Hand Maze. A single radiocarbon date from a cane charcoal fragment yielded a calibrated date of 975 BC or 2925 BP (Table 1). While not a direct dating of the art or gypsum mining, it gives us chronological context for Native American activity in the cave. The Early Woodland Period date is contemporaneous with the exploration and mining of Mammoth Cave, Salts Cave and other caves in the region.¹⁶

Native Americans clearly utilized 15Ed23 intensively and for a number of important purposes. Despite the disturbed cave environment, the site still contains many significant resources. We look forward to continuing our research at the cave, where we hope to assess passages that were inaccessible in the fall and winter, obtain additional chronological data, and further explore the site's remarkable past.

Acknowledgments

Thanks to Charlie and Catherine Bishop, Nick and Nate Noble, and all the 15Ed23 Project Cavers for their assistance. The current research was conducted under Kentucky Office of State Archaeologist Permit Number 2016-01.

Table 1: Radiocarbon Results from 15Ed23. Calibrated using INTCAL 13. By convention, BP (Before Present) is keyed to the calendar year 1950.

Laboratory No.	Material	Measured Age	d13C	Calibrated Date BP	Date Range BP (1σ)
Beta – 425352	cane charcoal	2860 +/- 30	-27.2o/oo	2925 +/- 30	2875-2960

Footnotes

1. Gary K. Soule, "Show Caves of Canada and the United States of America," *Journal of Spelean History* 23: (1-2): p. 14 [1989]; *The [Louisville] Courier-Journal*, March 5, 1922, p. 61; Charles B. Fort, "A Big and a Little Cave for Convention- goers," *The NSS News*, January 1953, pp. 1, 6; Roger Brucker, "Central Ohio Grotto Project One," *The NSS News*, December 1954, pp. 7, 8; Roger Brucker, "The Impossible Pit," in Charles E. Mohr and Howard N Sloane, eds., *Celebrated American Caves* (New Brunswick, N. J.: Rutgers University Press, 1955) : 78-89, Larry Griffin, "Second Crossing of 'Impossible Pit!'" *NSS News* September 1959, pp. 136-37.
2. Scrapbook from the Glenn Merrill Estate. In the private collection of Charlie and Catherine Bishop.
3. Duane De Paepe, *Gunpowder from Mammoth Cave: The Saga of Saltpetre Mining Before and During the War of 1812* (Hays, Kansas: Cave Pearl Press, 1985) p. 28.
4. Angelo I. George, "Saltpetre Activity in... Caves, Edmonson County, Kentucky," *The Karst Window*, 23: (1): p. 13 [1987].
5. J. H. Battle, W. H. Perrin, and G. C. Kniffin, *Kentucky. A History of the State* (Louisville and Chicago: Battey, 1885) p. 713; "Cedar Hill Cemetery, Princeton, Caldwell County, Kentucky, 1780-1998," <http://newsfeed.rootsweb.com/th/read/SATTERFIELD/2000-10/0970760142> Accessed 12-22-2015.
6. *Indiana Adj. Gen. Report*, Vol. not known, p. 666; "State News: List of Casualties in Indiana Regiments, at Murfreesboro," *Indiana State Chronicle*, January 26, 1863, p. 4; "Biography of Joseph L. Newman," U.S. National Park Service Soldiers and Sailors Database; John J. Hight, *History of the Fifty-Eighth Regiment of Indiana Volunteer Infantry* (Princeton, Indiana: Press of the Clarion, 1895) pp. 35-41.
7. Dr. William W. Blair, findagrave.com; William Wylie Blair (1827-1916) Papers, Manuscript and Visual Collections Dept., Wm Henry Smith Memorial Library, Indiana Historical Society; *The Journal of the Indiana State Medical Association*, Vol. 9 (Ft. Wayne: Indiana State Medical Association, 1916) p. 23; *Report of the Adj. Gen. of the State of Indiana*, Vol. 2, (Indianapolis: W. B. Holloway, 1865) p. 560.
8. Scrapbook from the Glenn Merrill Estate. In the private collection of Charlie and Catherine Bishop, p. 8.
9. Letter from Lee Hanson to Lymond Cutcliffe, April 2, 1964. Copy in possession of the authors.
10. Billy Reed, "Anybody Seen the Skeleton of Zelda?" *The [Louisville] Courier-Journal*, February 21, 1975, p. 5.
11. Clark Kissinger and Ted Will, *Baltimore Grotto Cave*, April 1960, pp. 73, 74.
12. Letter from Frank Fryman, Jr. to Campbell Grant, January 6, 1965. Copy in possession of the authors.
13. Letter from Fred E. Coy, Jr. to Philip J. DiBlasi, May 25, 1997. Copy in possession of the authors. Also see Letter from Fred E. Coy, Jr. to Nancy O'Mallely, August 21, 1997, Letter from Nancy O'Mallely to Fred E. Coy, Jr., September 3, 1997, and Letter from Philip J. DiBlasi to Dr. Fred Coy, May 30, 1997. Copies in possession of the authors.
14. Fred E. Coy, Thomas C. Fuller, Larry G. Meadows, James L. Swauger, *Rock Art of Kentucky* (Lexington: The University

Press of Kentucky, 1997); Philip J. DiBlasi, "Prehistoric Expressions from the Central Kentucky Karst," in Kenneth C. Carstens and Patty Jo Watson, eds., *Of Caves and Shell Mounds* (Tuscaloosa: University of Alabama Press, 1996) pp. 40-47.

15. "Jan F. Simek, Alan Cressler, and Elayne Pope, "Association between a Southeastern Rock-Art Motif and Mortuary Caves," in Carol Diaz-Granados and James R. Duncan, eds., *The Rock Art of Eastern America* (Tuscaloosa: University of Alabama Press, 2004) pp. 160-73.

16. George M. Crothers, Charles H. Faulkner, Jan F. Simek, Patty Jo Watson, and P. Willey, "Woodland Cave Archaeology in Eastern North America," in David G. Anderson and Robert C. Mainfort, Jr., *The Woodland Southeast* (Tuscaloosa: University of Alabama Press, 2002) pp. 502-24.

Excavation of an Early Nineteenth Century Brick Kiln at the Gardner House in Hart County, Kentucky

Lauren Kenney¹ and Darlene Applegate¹

¹ Western Kentucky University

Abstract

Located on the Western Kentucky University Green River Preserve, the Gardner House is one of the oldest standing brick structures in Hart County. Constructed ca. 1796-1810 by Thomas Coats, this hall-and-parlor house boasts unique architectural details including original interior doors, floors, and chair rails; Federal-style mantles and window recesses; a mortared limestone block foundation; and Flemish-bond brickwork with Munfordville cornices and door and window jack arches. Recent excavations of remains of the temporary brick kiln or “clamp” adjacent to the house provide insights into its construction. The 16 x 12 ft clamp was erected over a continuous hard clay floor up to 5 in thick. Green bricks were stacked on their stringer faces in different configurations to form three benches, which were separated by wide flues. The eastern side of the clamp was bordered by another bench or a brick wall that likely served as a wind break. After the bricks were fired, limestone was packed into the flues and burned to produce lime, creating a distinctive deposit that is partially fused to the clay floor below. After disassembling the benches, the loose lime was later mixed with sand in the flues to create the mortar and plaster used in the house construction.

Ethnographic Overview and Assessment of Mammoth Cave National Park: A Progress Report

Michael Ann Williams¹, Kristen Clark¹, Eleanor Hasken¹, and Rachel Haberman¹

¹ Department of Folk Studies and Anthropology, Western Kentucky University

Abstract

In fall 2015, the Department of Folk Studies and Anthropology at Western Kentucky University and the Kentucky Folklife Program embarked on an ethnographic overview and assessment of Mammoth Cave National Park, funded by the National Park Service and co-directed by Dr. Kate Hudepohl and Brent Björkman. The overall project will focus both on amassing and accounting for existing archival materials relating to the ethnography of the Mammoth Cave region, as well as conducting new ethnographic documentation of both tangible and intangible aspects of the culture of traditionally associated communities within the region. Undergraduate and graduate students enrolled in Field Methods, Applied Anthropology, Video Production, and Cultural Conservation have all been (or will be) engaged in various projects related to this grant. This panel will begin with an overview of the project by department head, Dr. Michael Ann Williams, and then will focus specifically on the cultural landscape survey being conducted this semester by graduate students enrolled in the Cultural Conservation course. The study area encompasses twelve USGS quads containing or bordering Mammoth Cave National Park. Six teams of students are studying two quads each. Each team will review all the records currently on file with the Kentucky Heritage Council, as well as other archival materials available at Mammoth Cave and other repositories. The students will conduct windshield surveys, document new structures and sites, update survey forms, and prepare study lists of potential National Register properties. Ultimately each team will prepare a summary report of cultural landscape resources for each quad and a final report will draw conclusions for the study area as a whole. After the project overview is presented by Dr. Williams, three graduate students will summarize the current findings for each of the twelve USGS quads and another student will provide a summary of the project accomplishments to date. Other team members will be available to provide answers to specific questions about individual structures and sites and the project's progress.

1852 Journey to Mammoth Cave StoryMap

Katie Algeo¹

¹ Department of Geography and Geology, Western Kentucky University

Abstract

In 1852, George Sargent took time off from the fall of his senior year at Harvard University to stay with his sister's family in Louisville, Kentucky. His diary from this period, recently acquired by WKU Special Collections, is a remarkable account of his journey by rail, stage, and steamboat from his home in New York City and his three-month sojourn in Kentucky, capped by a much-anticipated trip to Mammoth Cave. Sargent not only recorded his impressions of the cave, but also documented interactions with two of the cave's best-known guides, Stephen Bishop and Matterson Bransford, and with William Bell, proprietor of Bell's Tavern. This presentation demonstrates the use of a multi-media StoryMap, created via ESRI's ArcGIS online, to make portions of Sargent's diary more widely accessible through a web-based GeoApp. The StoryMap contextualizes Sargent's narrative with maps, period photographs, and commentary. The result is an engaging virtual journey that helps the viewer understand travel conditions and the situation of enslaved African Americans at a period of time over a century and a half ago, as well as, the enduring fascination of Mammoth Cave for travelers of all times.

Mammoth Cave: A Place Called Home

Cheryl Beckley¹

¹WKU PBS

Abstract

Mammoth Cave: A Place Called Home is a thirty minute documentary filled with personal stories of loss and change that came about in the early part of the 20th century with the creation of Mammoth Cave National Park. Historic and family photographs, along with historic footage of the Civilian Conservation Corps (CCC) taking down a pre-park home, bring history to life and reveal from different points of view how the creation of the park changed the people and the landscape of the Mammoth Cave region.

Where Did They Go? An Analysis of Out-Migration from Mammoth Cave National Park During Creation

Collins Eke¹

¹ Western Kentucky University

Abstract

The creation of national parks in the United States has often resulted in the displacement of resident populations. This is a study of out-migration from the area that would become Mammoth Cave National Park from 1926 until 1941. The purpose of this research is to underline the migration patterns of residents in this region. The 1920 census manuscript was used to determine who lived in the area, and these individuals were tracked using the 1930 and 1940 census manuscripts in order determine migration destinations. The analysis of the geography of out-migration shows a preference for areas that were close to their former homes or for larger urban areas. Consequences of this displacement are also considered. The two main migrant categories, African Americans and non-property owners, experienced higher levels of urbanization than the total displaced population. This suggests that urbanization of racial and socioeconomic groups was one of the consequences of park creation.

Flint Ridge Cave History and Legends

Norman L. Warnell¹ and Stanley D. Sides¹

¹ Cave Research Foundation

Barrel Hoop Cave

This is a shallow cave in a sinkhole near the bottom of Three Sisters Hollow. It was shown on an early topographic map of the area, so it may have been more extensive in the past.

Bedquilt Cave

Col. Bennett H. Young wrote this part of Colossal Cave was “- so named because of the finding there, some years ago, of an Indian mat resembling a quilt.” (Young 1910, p. 298) The cave served as a gypsum formation mine for locals, especially the Lee family.

When Milton H. Smith and the Louisville and Nashville Railroad were enjoined from entry into Woodson-Adair Cave in January 1896, Smith leased the Bedquilt entrance. Ed and Henry Lee found the way to connect to Colossal Cave from Bedquilt that allowed Edgar Vaughan and W. L. Marshall to survey the new entrance location. On October 14, 1896 for \$10, Isaac. N. Holton sold the cave rights on the land where the entrance to Bed Quilt lay to M.H. Smith of the L & N Railroad.

The cave entrance was open from about 1885 until the depression. Cave Research Foundation (CRF) caver Burnell Ehman entered the cave on a tour in the early 1930s. The entrance was 35 feet wide then, and visitors walked in the first part of the cave. Knowledge of the entrance location was lost until a CRF survey party on December 31, 1962 surveyed a crawlway to emerge on the surface.

Brill Cave

This small pit is not far from the Austin Entrance road. Donald and Frank Brill found the cave in June 1956 during a Central Ohio Grotto trip to Crystal Cave.

Breathing Cave

In Three Sisters Hollow there is an 8” high x 4’ wide cave entrance that blows much air and goes 90 feet to a waterfall. Bill Austin and Jack Lehrberger entered the cave as well as a later CRF survey party.

Buzzard Cave “alias” Cathedral Cave

According to Homer Collins in “The Life and Death of Floyd Collins,”

“The many-spined formations and columns in the cave led to the name Cathedral Cave. Originally, it was called Buzzards Cave. The buzzards roosted there and in the rock shelters nearby. Floyd used to climb up to their nests to steal eggs...”(Collins and Lehrberger 2001, p. 36).

Dr. Thomas ran an extended electrical line to the cave with several light bulbs in the cave. If visitors paid for a FCCC ticket, one got to visit Cathedral for “free,” as competition for Great Onyx Cave which also had electrical lighting.

The cave is important because of its rich fauna. Bro. G. Nicholas studied nocturnal migration of *Hadenoeus subterraneus* in the cave for his doctoral dissertation from November 1960 until 1962.

Colossal Cave

William Garvin sold on May 18, 1896, to Milton H. Smith, president of the L&N and 'trustee' for the Colossal Cavern Co. five acres ... "to make a surface entrance unto any and all caves and caverns under the land..." and ... "right of way for an electric railroad over the top" of the remainder of land owned by William Garvin.

The Colossal Cave was considered the large trunk passage reached by crossing over Colossal Dome from the Woodson-Adair entrance. Lyman Hazen had a 1/3 interest with Mary Isenberg and her father, Billie Adair, to develop Woodson-Adair Cave as a show cave. His 6-months interest was due to expire January, 1896, so Hazen sold his interest to Smith on Jan 24, 1896 for \$4500 in stock in the Colossal Caverns Company, with an additional \$500 to be received when he proved the river in Proctor Cave owned by L&N connected to the river in Colossal Cave.

As part of the agreement Hazen was to buy surrounding land for the Colossal Cavern Company as the railroad was not to take land for non-railroad purposes. Hazen was made manager of Colossal Cave when the new entrance opened in the summer of 1896.

At Woodson-Adair, then later when Colossal was opened, Hazen mined large quantities of formations from the cave. His contracts allowed him to sell formations and get revenue from any cabins, but he was deemed to be mining too much. Furthermore, he was not to compete with Colossal Cave by opening other caves.

Hazen fell into disfavor, and did not turn land over to the railroad's agent Daniel Breck on request as he had agreed.

L&N called for him to transfer his land on February 13, 1897, but he only transferred part of his holdings. He opened Hazen's Cave into Colossal Cave, forcing L&N to purchase this tract. All his rights at Colossal Cave were lost and he soon opened the Pike Chapman Entrance of Salts Cave in competition with Colossal Cave. J. M. Hunt replaced Hazen and became the manager of the Colossal Caverns in 1898.

Curd Cave

This Cave is located on land purchased from Richard Colman Estes in 1919 by E.C. Curd. His heirs sold 460 acres to the park movement in 1934. The cave was surveyed by CRF in the 1970s and consisted of winding canyons below the large sink shown on topographic maps on the east side of Houchins Valley.

Dickey Pit

Fred Dickey found this 50-foot shaft entrance to a low stream passage in Rigdon Hollow on a surface hike during CRF's Thanksgiving 1963 expedition.

Donkey's Cave or Floyd's Cave

This was Floyd Collins' first show cave. He purchased land across the valley from his home from George W. Cline. Floyd was plowing around the hillside in the winter of 1910 when the mule that was pulling the plow, fell through into a sink when the ground suddenly gave away, hence the name "Donkey's Cave."

Floyd died owing money on the property. Lee Collins, Floyd's father and heir, later simply "re-sold" the land back to Cline since it hadn't been paid for. Floyd built a

cabin over the shaft entrance and led some tours in the cave. Edmund Turner and Floyd Collins performed a survey of Salts Cave. This might have been to enable Collins to find further passages of Floyd's cave or a connection to Salts Cave, the Pike Chapman Entrance, which was just up the same hollow.

The Central Ohio Grotto re-explored and surveyed the cave in January 1956. Resurvey of the cave beginning Thanksgiving 2009 has led to connection of the cave to shafts off Pohl Avenue and integration into the Mammoth Cave System.

Elmore Cave

Short sandstone cave near the ridge top shown on topographic maps. The cave is named for African-American cave guide and underground worker Elmore Smith. He later worked for the Mammoth Cave Estate in the kitchen of the Mammoth Cave Hotel. The mystery about the cave is why this insignificant feature is shown on an early topographic map and those that follow.

Great Crystal Cave (Floyd Collins Crystal Cave)

According to Homer Collins, (Collins and Lehrberger 2001, p. 69) Floyd Collins first noticed the potential cave entrance in September 1917, with breakthrough December 17, 1917 beyond an entrance pit to the passages leading on. For several years, this and the other major Flint Ridge caves made up the longest surveyed cave system in the world.

Gothic Cave

The cave name is ambiguous but it does have limited speleothems that might have resembled to someone a miniature gothic cathedral. The cave is 132 feet long and is rich biologically. Gothic Cave and Curd

Cave were located on Richard Colman Estes' 460 acre tract of land at the time of the discovery of Woodson-Adair Cave. E.C. Curd later purchased this land, with his heirs selling it to the U.S.A. when the park was developed.

Great Onyx Cave

Much has been written on this famed Flint Ridge show cave discovered by Edmund Turner under the employ of L. P. Edwards beginning in 1915. A signature in the cave indicates Floyd Collins and Turner might have already been exploring the cave in 1914.

Hazen Cave

The Colossal Caverns Company (L&N Railroad) called for Lyman Hazen to transfer his land bought as land agent for the company on Feb. 13, 1897. Hazen only transferred part of the land. To the disgust of Smith, Hazen bought land adjacent to Colossal Cave property and forced an entrance into Colossal. He successfully opened Hazen's Entrance, which forced the L&N to buy the property to maintain control of all access to the cave. The shaft in Hazen's cave that led down to Colossal Cave was blasted shut.

Hog Cave

Hog Cave is located in sandstone at the valley edge on the Jacob Locke land near Bedquilt Cave. The cave resembles Elmore Cave around the ridge to the northwest. The five-foot drop at the entrance and very small stream make it unlikely it was used for livestock.

Ice Cave

Elkanah Cline on CRF recordings states:

"Dr. Hazen went into Salts, crossed

the valley, and came out Ice Cave. He blasted the passage in Ice Cave and it hasn't been found. Dr. Thomas was interested in Ice Cave because of this story. One used to enter Ice Cave, but it is now closed. It was used to store eggs in an alcove on the right side going in. It belonged to Tommy Johns."

Cline went back into the crevice 3-400 feet. Russell Neville photographed the entrance and wrote that locals got ice from the cave up until the summer months. Sawdust from the nearby Sell sawmill washed down the steep valley into the cave.

Johnson Cave

The Franklin Johnson homesite, spring, Johnson Cemetery and nearby Johnson Cave are close to the valley bottom between Collins Spring and the Dennison Ferry Road. CRF surveys began in November 1991. In July 1992 a survey party broke through the apparent cave end to discover virgin cave passages doubling the length of the cave.

Logsdon Cave

The Oscar Logsdon house site with the chimney still standing is directly across the hollow from the shallow sandstone Logsdon Cave entrance. Logsdon once worked for Floyd Collins Crystal Cave and also solicited for the New Entrance to Mammoth Cave.

Natural Tunnel

Bill Austin related a legend that the Collins' stored produce in Natural Tunnel before taking it to Horse Cave for sale. CRF entered the cave in 1968 and did a limited survey. No names or cultural items were recorded.

In May 2008 the cave was resurveyed and cultural features of the cave studied. There

is a small trail and dates suggesting Floyd Collins took individuals to the cave in 1920. There is no evidence of produce storage in the cave. A surface traverse over the cave revealed no evidence there ever was a developed back entrance.

Pagoda Cave

This cave name is as enigmatic as that of Gothic Cave. The cold trap entrance leads 140 foot in a high-ceilinged large migrating dome.

Potato Cave

The cave's name suggests that it was used store potatoes although it would have been a difficult endeavor to move potatoes in and out of the steeply sloping pit entrance of the cave. Famed Mammoth Cave guide Owen Josh Wilson owned the cave. His family retained ownership of the cave when they sold the rest of their land to W.O. Holton. Lyman Cutliff was familiar with the cave. The cave was the first cave CRF surveyed on the northwest part of Flint Ridge beginning in 1961.

Rigdon Pit

Rigdon Pit was found in 1963 during the discovery of nearby Dickey Pit but its difficult vertical shaft series was not surveyed until a series of CRF trips in the summer of 1971.

Salts Cave

In 1910 Col Bennett H. Young wrote:

"No definite statement as to the discovery of Salts Cave can be found. After inquiry among the oldest men now residing in that locality, including Squire O.P. Shackelford and Mr. A.B. Johnson, both of whom have lived all their

lives near the place, it is probable that the first white man who ever saw the cave was William West who it is said patented the land covering it about 1794. Squire Shackelford distinctly recollects his father telling him, when he was quite a young man, that the cave was explored first by Peter Kinser, who, upon entering it, remained in it a week examining its passages, and Squire Shackelford's wife found a moccasin in Salts Cave in 1851" (Young 1910, pp 208-209).

At one time three different parties claimed ownership to this cave; i.e. the Mammoth Cave Estate, Mark Thompson, and Lark Burnett. At the creation of Mammoth Cave National Park, a court case resulted in the heirs of Burnett being the rightful owners and receiving compensation for the land and cave.

Pike Chapman Entrance to Great Salts Cave

Jacob Jones purchased from Benjamin Payne, 150 acres of land on Flint Ridge in 1854. Jones began clearing the land and within twenty years had a good rail fence around his fields where he maintained a 'picturesque' farm, and the cleanest fence rows of any farmer on Flint Ridge.

However, he soon became restless and in 1877 sold the farm to Caroline and Lewis Vials of Horse Cave KY. Lewis Vials hired two French surveyors to survey Salts Cave and found that the cave ran beneath his property.

The Blue Grass Country Club was later located on this land in the early 20s. The large 440-acre survey had a section purchased by E.W. Johnson, brother-in-law of L.P. Edwards. Johnson sold this land to

L.W. Hazen in 1896. It was upon this land that the Pike Chapman entrance to Salts Cave was located. In July 1897, Hazen was enlarging the Pike Chapman entrance to show the cave when Pike, Hazen's nephew, died in an entrance rock collapse.

In August 1897, the Louisville Courier-Journal printed a full page article "Rivals the Mammoth Cave in Grandeur." It was the last straw for Smith and Daniel Breck. L&N took Hazen and his wife to court taking all of the land they had in the area, including the Pike Chapman Entrance, as the contract Smith and the Hazens signed had a provision that on demand they would turn over all the land they had in the area to Smith and the Colossal Caverns Company.

Floyd Collins and his brothers were hired by the Blue Grass Country Club to reopen the entrance in 1919 (Collins and Lehrberger 2001, p. 91) and guided cave tours for the club. The timbered entrance collapsed after the country club closed and has remained sealed.

Sheep Cave

The cave is an open shaft on the undercut south wall of Ice Cave that was doubtfully used by sheep.

Woodson-Adair Cave

This is the original entrance to Colossal Cave, and was named in for William Adair and Robert Garvin (alias Woodson), owners of the land under which the cave ran. It is likely that Woodson found the cave opening in early 1895 that was developed by Lute and Henry Lee.

Lyman Hazen moved his houseboat up the Green River to Mammoth Cave. The boat was moved overland to the Woodson-Adair Cave in September 1895 when Hazen reached an agreement with William Adair

and his daughter, Mary Isenberg, to develop the cave as a show cave.

Lyman and Sophronie Hazen lived in the galley while a five room one and a half story log house was constructed above the entrance to the cave. A trap door beneath the log house led down into the cave. Pike Chapman was lowered down a deep pit in the back of the cave named Colossal Dome and found the main trunk passages named “Colossal Cave.”

Unknown Cave

The cave has its entrance under a cliff in Three Sisters Hollow. The early exploration history of this cave is obscure, but it can be assumed that the cave was visited many times in the 1800s. Names found on the cave walls include several members of the Hunt and Lee families, local cave guides, explorers over several generations and the name of Edmund Turner.

The 50-acre tract containing the cave was west of the Vials land and very near Floyd Collins’ Donkey Cave and the Pike Chapman Salts Cave entrance. A.J. Monas

and family were living here in the late 1850s. The land soon passed to P.C. Padgett. Padgett eventually sold this farm in 1897 to Lyman Hazen.

The cave subsequently was owned by L&N Railroad and leased to the Blue Grass Country Club. Exploration in 1954 down shafts in Unknown Cave by Louisville Grotto cavers and Bill Austin with Jack Lehrberger led to discovery of the central passages of the Flint Ridge Cave System.

References cited:

Collins, Homer, and John L. Lehrberger. 2001. *The Life and Death of Floyd Collins*. Cave Books, St. Louis, 206 pp.

Young, Col. Bennett H. 1910. *The Prehistoric Men of Kentucky*. Filson Club, Louisville, 314 pp.

Research and Resources in Western Kentucky University Special Collections

Nancy Richey¹

¹ WKU Special Collections Library, Western Kentucky University

Abstract

This presentation offers a look at the Mammoth Cave resources available at the Department of Library Special Collections on Western Kentucky University's campus. At the library, these public resources are available for students, faculty and visiting scholars. These materials, such as a complete set of Charles Waldack's underground magnesium views, encourage original research into the study of the cave and associated phenomena, and other supporting cave and karst research. The library is continually collecting speleological information and maintains a library with a large collection of books and journals on caving topics as well as primary resource materials that can aid professionals in historical as well as karst hydrology, archaeology, and geology fields of study. Researchers will be introduced to two access portals, KenCat and TopSCHOLAR. TopSCHOLAR is the digital repository and publishing platform that provides open access to scholarly works created by the faculty, students, and staff of Western Kentucky University.

The Freshwater Mussels and the Green River: Conservation, Protection, and Management of a Vital Resource in North America.

Monte McGregor¹

¹ Kentucky Department of Fish and Wildlife Resources

Introduction

North America hosts the most diverse freshwater mussel fauna on Earth (Haag 2010), with approximately 300 species representing 36% of the total global mussel diversity (Cummings and Graf 2009). Kentucky has one of the most diverse mussel populations in North America, with 41 genera and 105 recognized species, representing 35% of the fauna. In Kentucky, 12 mussels are presumed extinct, and another 27 are listed by the U.S. Fish and Wildlife Service as Threatened or Endangered. Nine of the 27 are considered extirpated from the state. Kentucky also has 46 species on the list of Species of Greatest Conservation Need. Threats to mussels include habitat destruction, water pollution, sedimentation, isolation due to impoundments or chemical barriers, lack of fish hosts, and more. Mussels have a complicated life cycle, and each mussel depends on a host fish to complete the delicate life stages from egg, larvae (on the host), juvenile, to adult (which may last decades) (Figure 1).

The Green River historically supported a few hundred to a few thousand species of mussels, snails, fishes, crayfishes, aquatic insects, reptiles, amphibians, birds, mammals, plants, etc. The Green River system includes the world's largest cave system (Mammoth Cave) and its surrounding freshwater and terrestrial ecosystems make it a hotspot for biological diversity. The River, especially the upper

Green River, is rated fourth in the US for the highest aquatic biodiversity. The most significant stretch is the 114 un-impounded river miles between Lock and Dam 6 in Mammoth Cave National Park and Green River Lake Dam on the upper end. It is especially rich in fishes and freshwater mussels.

The Green River has 74 species of freshwater mussels (or 71% of all KY species) and ~ 150 species of fishes. Twenty five percent (25%) of all North American mussel species are found in the Green River. Six of the 74 are considered extirpated from the Green. There are 17 Threatened and Endangered mussels in the Green, representing 16% of the T&E mussel species in the state and 32% of all US listed mussel species (88 species listed by the USFWS in 2014). Of the 74 species, KDFWR has identified 28 (or 38%) as species of greatest conservation need. Nine of the 17 Threatened and Endangered species can still be found in the Green

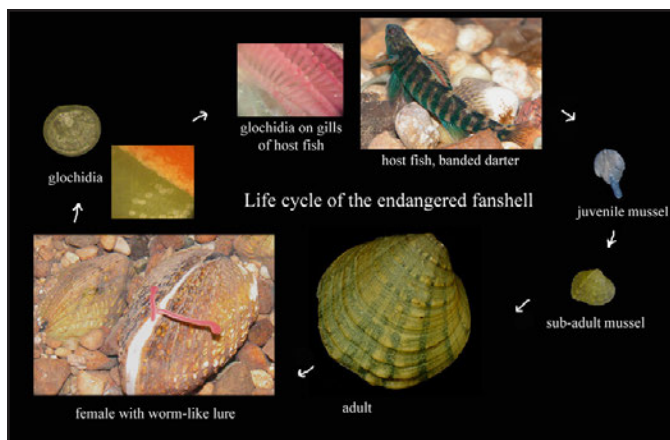


Figure 1: The life cycle of the endangered fanshell, *Cyprogenia stegaria*.

River. The Green River is currently home to several endangered mussels, including the ring pink, *Obovaria retusa*; fanshell, *Cyprogenia stegaria*; rough pigtoe, *Pleurobema plenum*; clubshell, *Pleurobema clava*; pink mucket, *Lampsilis abrupta*; sheepnose, *Plethobasus cyphus*, rabbitsfoot, *Quadrula c. cylindrica*, orangefoot pimpleback, *Plethobasus cooperianus*, fat pocketbook, *Potamilus capax*, and spectaclecase, *Cumberlandia monodonta*. It also supports one endemic mussel, the Kentucky creekshell, *Villosa ortmanni*. Of all the T&E species found in the Green, the rabbitsfoot, rough pigtoe, sheepnose, clubshell, fanshell, and spectaclecase seem to be doing the best. The fanshell has the best populations of all T&E species, with multiple sites showing recruitment.

Background: Center for Mollusk Conservation

In 2002, the Center for Mollusk Conservation (CMC) initiated propagation efforts for many of the rare and imperiled freshwater mussels in KY. The CMC has a modern facility with a greenhouse, research lab, fish research building, algae culture capabilities, and much more. With several full time staff, the CMC has made considerable advances in the area of mussel life history, propagation, and culture. In 2005, the CMC initiated work with the endangered pink mucket (*Lampsilis abrupta*), and the non-listed black sandshell (*Ligumia recta*) for augmentation in the Green river (Figure 2). Both species are rare in the river, and researchers have only observed a few pink muckets in the last 10 years. Augmentations have been undertaken to boost the pink mucket populations starting in 2005, and continuing in 2011 through 2015. Several thousand juveniles have been cultured and released at multiple sites. Ongoing monitoring is



Figure 2: Juveniles of the endangered pink mucket, *Lampsilis abrupta*, reared at the Center for Mollusk Conservation, and released in the Green River.

being conducted to check the status of the augmentations and track recruitment of other species at long-term monitoring sites. Much work is needed on the development of propagation and culture methods for Green River and other Kentucky mussel species, especially those that life history work is limited or unknown. Host fishes are still questionable for many mussels, especially natural hosts. However, the CMC researchers have developed techniques to bypass or skip the fish host using incubators and modern cell culture methods. As of 2016, CMC biologists have transformed over 50 species without a host. Without concentrated effort on many of the species, more animals are expected to become listed as federal endangered or even extirpated from Kentucky.

Materials and Methods: Monitoring the Freshwater Mussel Populations in the Green River.

In 2004, the CMC initiated a monitoring program to quantitatively examine the mussel populations at select sites in the Green River. Herein is reported on one site near Munfordville that was examined

in 2004, 2009, and 2014. Assessment of the mussel population was designed to determine species presence for abundant (> 1.0 mussel/m²), common (0.5 to 1 mussel/m²), ($>$ rare (0.1 mussel/m²), very rare species (0.001 to 0.01 mussel/m²), estimate population density, estimate size structure to indicate recent recruitment (individuals < 50 mm in length), and to establish guidelines for monitoring the site and others over time (i.e., establish long-term trends). First, we defined the Grid Area (i.e., the specific area where the quantitative sampling would be conducted) as the upstream and downstream boundaries of the mussel bed in question by using previous qualitative survey information (i.e., surveying the area using snorkeling techniques under low water conditions). For practical purposes, we quantified the Grid Area as a rectangular area that included boundaries upstream, downstream, and two parallel lateral banks. We divided the area into 20m long x n (20m x n width), where n is equal to the number of one meter wide longitudinal transects, each containing 20-1 m² cells. We selected a 1 m² quadrat size to minimize the number of cells with no mussels, and to increase the amount of area surveyed relative to total sample area. We recommend a sampling fraction of 5 percent for areas $> 5,000\text{m}^2$, and 0.10 for areas $\geq 500\text{m}^2$ and $< 5,000\text{m}^2$ based on Smith et al. (2001).

At each location, the size of the grid (width of stream) was measured using a fibered measuring tape, and the lower (downstream) left corner was established as a reference point. Photos were taken to document the grid boundaries and longterm markers (permanent boulders or geographic features) were noted. The number of possible segments (i.e., 3m x 20 m blocks= 60m^2) was determined by multiplying the area ($\sim 1,000\text{m}^2$) x 10-20% sampling fraction (100 to 200

samples needed), selecting the number of teams available (in this case 12), and picking a minimum of 10-20% of 60 (6-12 samples within each block). For example, 150 samples divided by 12 teams would reflect ~ 12 samples per block (=144 per grid) and would fall in the middle of the sampling fraction desired. Once the possible number of segments was identified (in this case-16), the number of random samples taken by segment was selected. Twelve blocks were randomly chosen from the maximum 16 possible, and 12 random samples were collected within each block. This provided equal sampling effort within a block to allow comparisons between blocks and improved logistics on locating coordinates.

Results: Mussel Monitoring

Thirty three species were collected at the site from 144 samples (n=432 samples) in each of three years (Table 1, Figure 3). Population estimates for all mussels in the grid ranged from 6,500 to 7,900, with estimates for the entire bed being 39,000 to 47,000, with the highest densities observed in 2014. The bed size in the entire riffle is approximately 50m x 120m (=6,000 m²). The most abundant species was the mucket, making up from 32 to 72% of the total abundance (Table 2).



Figure 3: Mussel assemblage from the Green River, typical of an assemblage in Mammoth Cave National Park.

Table 1: List of the mussels collected in the Green River at the Sampling Site in 2004, 2009, and 2014.

	2004			2009			2014		
SPP	#	%	# / m	#	%	# / m	#	%	# / m
<i>Actinonaias ligamentina</i>	987	71.21	5.483	378	32.64	2.124	532	36.61	2.923
<i>Elliptio dilatata</i>	18	1.30	0.100	91	7.86	0.511	189	13.01	1.038
<i>Amblema plicata</i>	68	4.91	0.378	68	5.87	0.382	98	6.74	0.538
<i>Quadrula pustulosa</i>	18	1.30	0.100	53	4.58	0.298	98	6.74	0.538
<i>Cyclonaias tuberculata</i>	64	4.62	0.356	161	13.90	0.904	97	6.68	0.533
<i>Pleurobema sintoxia</i>	20	1.44	0.111	60	5.18	0.337	73	5.02	0.401
<i>Quadrula metanevra</i>	33	2.38	0.183	87	7.51	0.489	59	4.06	0.324
<i>Cyprogenia stegaria</i>	13	0.94	0.072	54	4.66	0.303	52	3.58	0.286
<i>Lampsilis ovata</i>	19	1.37	0.106	29	2.50	0.163	45	3.10	0.247
<i>Fusconaia subrotunda</i>	34	2.45	0.189	33	2.85	0.185	44	3.03	0.242
<i>Megalonaias nervosa</i>	42	3.03	0.233	54	4.66	0.303	36	2.48	0.198
<i>Ptychobranhus fasciolaris</i>	18	1.30	0.100	13	1.12	0.073	35	2.41	0.192
<i>Lampsilis fasciola</i>	1	0.07	0.006	10	0.86	0.056	28	1.93	0.154
<i>Quadrula verrucosa</i>	0	0.00	0.000	0	0.00	0.000	0	0.00	0.000
<i>Lampsilis cardium</i>	0	0.00	0.000	2	0.17	0.011	14	0.96	0.077
<i>Lasmigona costata</i>	8	0.58	0.044	5	0.43	0.028	11	0.76	0.060
<i>Ligumia recta</i>	1	0.07	0.006	3	0.26	0.017	9	0.62	0.049
<i>Strophitus undulatus</i>	1	0.07	0.006	3	0.26	0.017	8	0.55	0.044
<i>Lampsilis abrupta</i>	0	0.00	0.000	0	0.00	0.000	6	0.41	0.033
<i>Potamilus alatus</i>	0	0.00	0.000	3	0.26	0.017	5	0.34	0.027
<i>Plethobasus cyphus</i>	7	0.51	0.039	1	0.09	0.006	4	0.28	0.022
<i>Leptodea fragilis</i>	1	0.07	0.006	5	0.43	0.028	3	0.21	0.016
<i>Elliptio crassidens</i>	3	0.22	0.017	3	0.26	0.017	2	0.14	0.011
<i>Pleurobema cordatum</i>	6	0.43	0.033	13	1.12	0.073	2	0.14	0.011
<i>Pleurobema rubrum</i>	0	0.00	0.000	0	0.00	0.000	1	0.07	0.005
<i>Quadrula cylindrica</i>	5	0.36	0.028	3	0.26	0.017	1	0.07	0.005
<i>Truncilla truncata</i>	10	0.72	0.056	8	0.69	0.045	1	0.07	0.005
<i>Alasmidonta marginata</i>	0	0.00	0.000	3	0.26	0.017	0	0.00	0.000
<i>Ellipsaria lineolata</i>	1	0.07	0.006	1	0.09	0.006	0	0.00	0.000
<i>Fusconaia flava</i>	0	0.00	0.000	1	0.09	0.006	0	0.00	0.000
<i>Obliquaria reflexa</i>	7	0.51	0.039	9	0.78	0.051	0	0.00	0.000
<i>Pleurobema plenum</i>	1	0.07	0.006	3	0.26	0.017	0	0.00	0.000
<i>Quadrula quadrula</i>	0	0.00	0.000	1	0.09	0.006	0	0.00	0.000
Totals	1386	100.00	7.7000	1158	100.00	6.5056	1453	100.00	7.983516

Average mucket densities ranged from 2.1 to 5.4/ m², with population estimates from 10,617 to 27,416. Juveniles (< 50mm) made up 5.8 percent of the mucket population, indicating good recruitment in 2012 and 2013. In 2004 and in 2009, only 1 species, the mucket, was considered abundant (> 1/ m²), and 22 species were rare (less than 0.1 m²). In 2014, two species, the mucket and threeridge, were abundant and 20 species were rare. In 2004, 11 species made up 95% of the population, compared to 14 in 2009, and 13 in 2014. In 2009 and 2014, 5 species made up ~70% of the population, compared to 1 species in 2004. The community in 2014 is more even in species distribution compared to 2004. Several species are increasing in numbers and the population is growing. The endangered fanshell ranged from 0.07 to 0.30/m² in the 10 year period, with population estimates from 72 to 303 in the grid, and 433 to 1,820 individuals in the entire bed. All species listed as abundant and common showed evidence of recruitment, and even uncommon species had 1 or 2 juveniles observed in the sampling effort.

The mussel population at this site in the Green River seems to be on the increase, at least with about one half of the species observed in the grid. Each riffle/run/pool sequence in the Green supports slightly different proportions of individuals and may provide low levels of recruitment to beds with lower densities. It is important to

protect as many areas as possible to ensure that strongholds are present for all species in the river. If areas where densities of at least 0.1/m² are not present, then the likelihood of that species disappearing from the Green is high in the next generation for that species. Management of the species should include monitoring of enough sites to determine the critical low population trends and levels of the rare species. Decisions can then be made on actions needed, such as augmentation and translocation. Hatcheries can focus on production of the species that are showing limited or no recruitment to produce juveniles and enhance populations.

Literature Cited

- Cummings, K.S. & D.L. Graf. 2009. Mollusca: Bivalvia. pp. 309-384 in J.H. Thorp & A.P. Covich (eds.). Ecology and Classification of North American Freshwater Invertebrates, 3rd edition. Academic Press-Elsevier, New York.
- Haag, W. 2012. North American Freshwater Mussels: Natural History, Ecology, and Conservation by Cambridge University Press.
- Smith, D. R., R. F. Vilella, and D. P. Lemarie. 2001. Survey protocol for assessment of endangered freshwater mussels in the Allegheny River, Pennsylvania. Journal of the North American Benthological Society 20:118–132.

Table 2: Relative density comparisons in categorical grouping by year.

Density	Category	2004	%	2009	%	2014	%
# species >1/m ²	abundant	1	71	1	33	2	50
# species 0.5 to 1/m ²	common	0	0	2	21.8	3	20.2
# of species 0.1 to 0.5/m ²	uncommon	10	24	8	37.8	8	25.6
# of species < 0.1/m ²	rare	22	5	22	7.8	20	4.6
Total # species comprising 95% of abundance	11		14		13		

In Situ Survival and Performance of Juvenile Mussels in Streams and Correlations with Water and Sediment Quality Factors

Wendell Haag¹, Jacob Culp², Monte McGregor³, James Stoeckel⁴, and Robert Bringolf⁵

¹ United States Forest Service

² Kentucky Division of Water

³ Kentucky Department of Fish and Wildlife Resources

⁴ Auburn University

⁵ University of Georgia

Abstract

Freshwater mussels have disappeared or declined greatly in many streams. In some cases, mussel declines appear linked to specific factors such as coal mining, but mussels also have declined in many streams that have no obvious human impacts. We directly examined survival and growth of juvenile mussels in 23 streams across Kentucky. These streams represent a range in conditions from streams that support largely intact mussel assemblages to those that have lost their mussels almost entirely; seven streams fell into this latter category. In each stream, we placed captively propagated juvenile pocketbooks (*Lampsilis cardium*, 6 months old, mean length = 6.4 mm) in silos and sediment cages in late May and early June and retrieved them in September. We also collected water and sediment samples monthly during the study and monitored stream temperature continuously. Mussels showed high survival in nearly all streams, regardless of the condition of the resident mussel assemblage. However, juveniles grew little in all seven streams that have lost their mussel fauna. These mussels appeared to be starving and likely would have died shortly. Mussels grew in all other streams, but growth varied widely probably in large part according to natural variation in basin geology and water chemistry (e.g., temperature, productivity, water hardness). We currently are investigating the potential role of other water and sediment chemistry variables in explaining the lack of growth we observed at some sites; these results will be discussed as available. This study suggests that disruption of mussel feeding or a change in mussel food resources in streams may be a major factor in mussel declines.

Potential Evidence for Arsenic Mineralization in Mussel Shells in the Upper Green River Basin, Kentucky

Autumn Turner¹, Chris Groves¹, Aaron Celestian² and Albert Meier³

¹ Crawford Hydrology Laboratory, Western Kentucky University

² Natural History Museum of Los Angeles County

³ Department of Biology, Western Kentucky University

Introduction

Harvesting and burning of fossil fuels results in the release of numerous derivatives known to be detrimental to the environment and its fauna. Environmental conditions within Kentucky's Green River Basin are impacted by emissions from various regional coal burning power plants. Emissions from these activities contribute to acid deposition/precipitation. Coal burning increases atmospheric CO₂ concentrations that in turn lower rainfall pH, and sulfur within the mineral pyrite (FeS₂) often contained within coal can be oxidized to contaminate rainwater with sulfuric acid. Other byproducts associated with coal power production include toxic metals including mercury and arsenic that can be deposited onto land and water surfaces.

Together, these major contributors to surface water acidification can pose substantial threats to aquatic biota, particularly among calcifying organisms. Aquatic systems are very sensitive to associated changes in water chemistry and concerns exist that biodiversity may suffer as a consequence. Economic motivations have called for study into the effects of lowered pH on the dissolution of calcite shells in marine molluscs as it relates to community and population health. The results of these studies indicated that decreases in pH lead to significantly higher mortality rates in juvenile mussels, including death by dissolution (Green, 2004) and impaired periostracum repair in adults (Rodolfo-Metalpa, 2011). Less well studied is whether human impacts on atmospheric chemistry with regard to pH or other characteristics may be impacting, and whether evidence for these impacts is present in the shells of mollusks such as mussels in fresh water ecosystems. These organisms are an important component of the biodiversity within Kentucky's Green River Basin.

The purpose of this exploratory study sought to determine whether there is mussel shell evidence of ecological impact of emissions from regional coal power production including the TVA Paradise Fossil Plant and others by examining shell mineral constituency of *Actinonaias ligamentina*, a common freshwater mussel species. We examined shell material collected in about 2000 (Kirkland, 2002) from Lawler Bend on the Green River, several kilometers upstream from Mammoth Cave National Park (MACA). This part of the Green River Basin has been shown to be impacted by fallout from coal combustion, with historically lowered rainfall pH and elevated sulfate concentrations based on data from the Houchin Meadow atmospheric monitoring station near MACA (NADP, 2016).

Evolution of the Evidence

In an evolving sequence of events, we began by analysis of shell thin-section (Figure 1) within a transect across annually deposited shell layers with Raman Spectroscopy. In



Figure 1: Scanned image of *Actinonaias ligamentina* shell thin section used in Raman Spectroscopy mineral analysis.

this process samples are excited with a laser beam, and analysis of the resulting electron scattering emanating from the regions where the beam impacts the sample provides information on molecular vibrations in the system, which in turn can be used as a “fingerprint” to identify the constituent molecules present. For solid mineral samples, comparison of these data with existing libraries of spectrum data can identify constituent minerals present that make up a sample. As expected, the great bulk of the shell through the central region was composed of calcium carbonate

(CaCO_3) in the form of aragonite. However, bands on the inside and outside of the shell showed a different distribution of Raman Spectra (Figures 2 and 3). An analysis of one of these spectra (Figure 4) to our surprise indicated the presence of the relatively rare ferrous sulfate-arsenate mineral bukovskyite ($\text{Fe}_2(\text{AsO}_4)(\text{SO}_4)(\text{OH}) \cdot 7\text{H}_2\text{O}$), also historically known as the poisonous “clay of Kutná Hora.” Figure 4 shows a comparison of the sample’s Raman spectrum with the library standard, showing a close correlation of relevant peaks. If the mineral is indeed found within the shell, it may suggest that these organisms have directly bioincorporated the material into the shells during formation of annuli. To our knowledge, bukovskyite has never been identified or described as present in the shells of freshwater mollusks.

An immediate question that arises would be to identify the sources of these various constituents, in this case arsenic (As), sulfur (S) and iron (Fe). It is clear that coal burned through the years at regional power plants over the tens of years that the mussel growth represented contains the mineral pyrite, particularly coal from western Kentucky

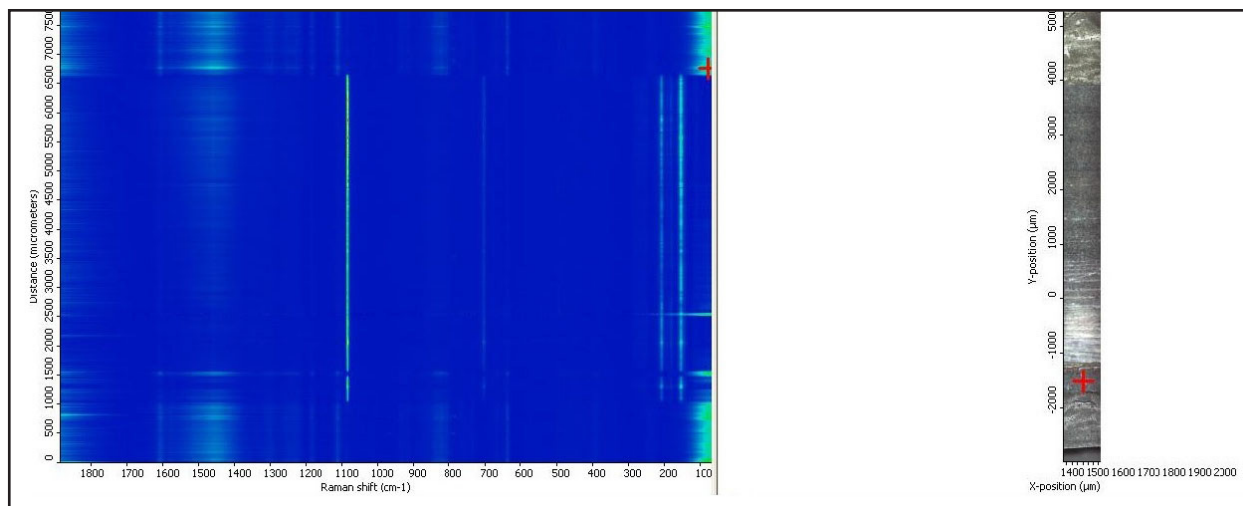


Figure 2: Distance vs. Raman shift for entire section of *Actinonaias ligamentina* shell analyzed.

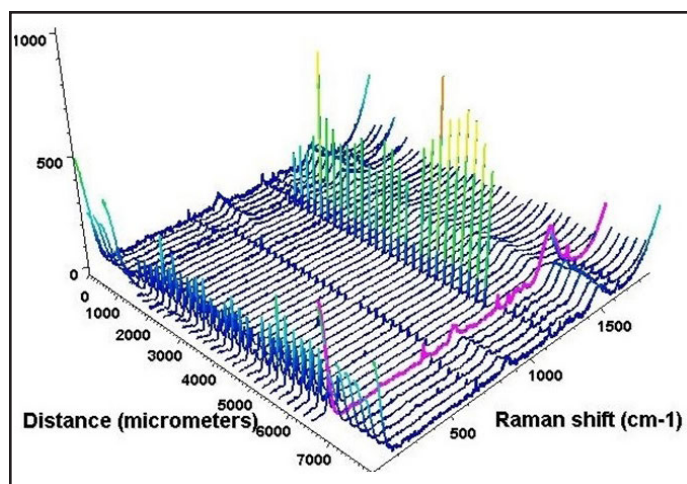


Figure 3: Topographic representation of Raman spectra generated from entire *Actinonaias ligamentina* shell analysis.

that was burned during years before being augmented/replaced by lower sulfur coals from Wyoming's Powder River Basin. Within coal, arsenic can be associated with pyrite as 1) arsenic-rich pyrite, within which some iron has been replaced by arsenic up to about 10% by weight, 2) as the mineral arsenopyrite (FeAsS), or 3) as arsenate (AsO_4^{3-}) (Huggins et al. 1993; Huffman et al., 1994). Upon combustion, within coal ash this is generally present as arsenate species.

Our team decided that an additional, independent identification of the presence of bukovskyite, or at least arsenic, would be important to confirm the Raman spectroscopy results. We first investigated the thin section under a Scanning Electron Microscope (SEM) with attached capacity for Energy Dispersive Spectroscopy (EDS), which has the ability to provide elemental analysis for near surface layers. Examining the regions that had shown the unusual spectra, and not knowing whether the bukovskyite, if present, was evenly disseminated throughout that region of the shell or was isolated as discrete particles, we focused the fine (micron scale) beam on

heterogeneous light and dark spots and found no indication of arsenic. It is not clear from these results whether there 1) is not arsenic in the samples, 2) whether we did not examine the right microscopic sites, or 3) whether arsenic is present but at concentrations below the detection limit of the EDS technology.

We then worked to digest in acid solutions an amount of powdered sample, from another of Kirkland's (2002) shells collected downstream from the first one that had already been ground to run the resulting fluid on Inductively Coupled Plasma Optical Emission Spectroscopy (ICP OES) which is able to measure trace elements with high sensitivity. After dissolving in a hydrochloric/nitric acid solution there was still some insoluble residue, and so a second digestion using hydrofluoric acid was completed. There was still a small amount of insoluble material present and so a third digestion, using a lithium tetraborate dissolution technique at 1050°C . A small amount of insoluble residue remained still. ICP OES analysis of the fluid showed no arsenic above the detection limit, and Raman Spectroscopy analysis of the insoluble crystals indicated that these are made of quartz. We are uncertain as to whether there was no arsenic in this sample, or whether what was present was below the detection limit. Ongoing efforts will work to grind samples from the same shell from which the bukovskyite Raman spectrum was obtained, and to repeat this analysis with a larger quantity of shell material digested.

Conclusions

Although the Raman spectrum showing a close match to bukovskyite is consistent with the potential presence in the Upper Green River basin of arsenic-bearing pyrite species or byproducts from coal combustion, at this

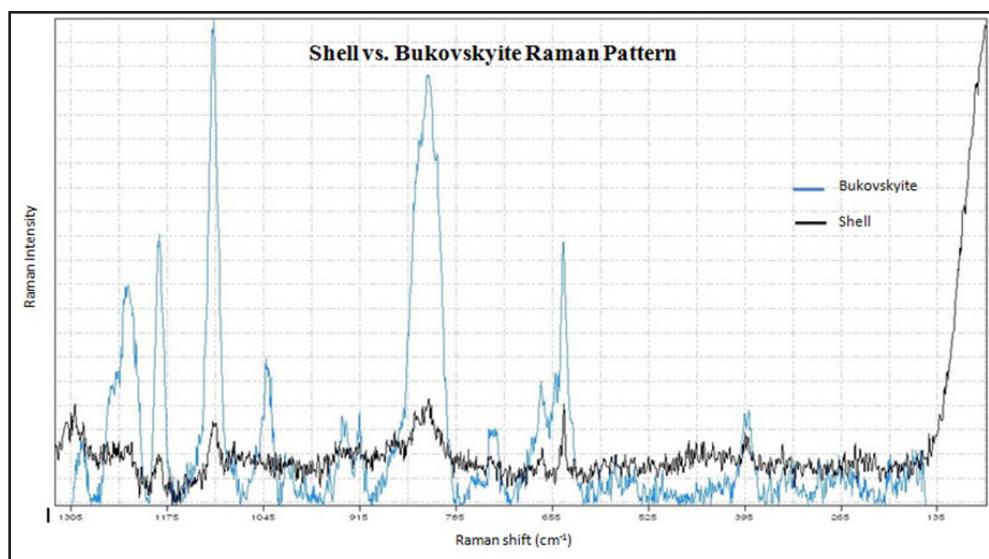


Figure 4: Raman pattern of shell vs. Bukovskyite pattern from CrystalSleuth® mineral database.

stage we are left to further consider what this discrepancy of findings might suggest and how this may affect the prospects for identifying mussel individuals exposed to arsenic species associated with coal combustion. Raman spectroscopy is a powerful tool for determining the mineral constituency of a material and the apparent close match of the spectrum generated from examination of inner and outermost layers of the shell to a known standard spectrum gives cause to continue exploring along these lines. Currently, we have not ruled out the possibility that arsenic is present within the shell sample based on lack of support from EDS spectroscopy for several reasons as discussed above. The point of interest in this research is that if mussels in the Green River are bioincorporating these arsenic derivatives associated with coal combustion fallout processes, it may be possible to reconstruct a biologically preserved record of changes in coal-burning emissions in the region from mussel specimens that were extant in periods coincident with atmospheric conditions prior to Clean Air Act Title IV emission stack modifications

and the switch to burning lower sulfur coal as well as those conditions present post-modifications.

References

- Green, M.A., Jones, M.E., Boudreau, C.L., Moore, R.L., & Westman, B.A. (2004). Dissolution mortality of juvenile bivalves in coastal marine deposits. *Limnology and Oceanography* 49: 727-734.
- Huggins, F.E., Shah, N., Zhao, J., Lu, F. and Huffman, G.P. (1993). Nondestructive determination of trace element speciation in coal and coal ash by XAFS spectroscopy. *Energy & Fuels* (7): 482-489.
- Huffman, G.P., Huggins, F.E., Shah, N. and Zhao, J. (1994). Speciation of arsenic and chromium in coal and combustion ash by XAFS spectroscopy. *Fuel Processing Technology* (39): 47-62.
- Kirkland, R. (2002). *Actiononaias ligamentina as a biomonitor in the Green River: An unique approach for analysis of environmental impacts*. Bowling Green, KY: Western Kentucky University Master's

thesis. Accessed online at: (< <http://digitalcommons.wku.edu/theses/605/> >). (Accessed November 3, 2015).

National Atmospheric Deposition Program. (2016). Weekly samples for site: KY10 (Mammoth Cave National Park-Houchin Meadow). Accessed online at: (< <http://nadp.isws.illinois.edu/nadpdata/weeklyReport.asp?action=weeklyReport.asp&site=KY10&allSites=False&wholestate=False&custom=False&startmonth=01&startyr=2002&endmonth=10&endyr=2015&reportType=html&useType=1&useDescription=Thesis+research&submit=Get+Data&userid=331782> >). (Accessed February 13, 2016).

Rodolfo-Metalpa, R., Houlbreque, F., Tambutte, E., Boisson, F., Baggini, C., Patti, F.P., Jeffree, R., Fine, M. Foggo, A., Gattuso, J.P., and Hall-Spencer, J.M. (2011). Coral and mollusc resistance to ocean acidification adversely affect by warming. *Nature Climate Change* 1: 308-312.

Surveys for the Diamond Darter (*Crystallaria cincotta*), an Endangered Species Known Historically from the Green River in Kentucky

Matthew R. Thomas¹, Stephanie L. Brandt¹

¹ Fisheries Division, Kentucky Department of Fish and Wildlife Resources

Abstract

The Diamond Darter formerly occurred in the Ohio River basin in Kentucky, Tennessee, Ohio, and West Virginia; however, it is now extant only within a 22-mile section of the Elk River in west-central West Virginia. Due to its decline and currently restricted range, the Diamond Darter was federally listed as endangered in 2013. In Kentucky, the species is known only from six pre-1930 records: lower Cumberland River (1 record), upper Green River (3 records), and Ohio River (2 records). It was last collected in the Green River near Cave Island, Edmonson County, in 1929. Extensive sampling for fish in the middle and upper Green River during the past 30 years using seines and electrofishing (backpack and boat units) has failed to detect the species. The Diamond Darter is difficult to collect using standard sampling methodologies because it is nocturnally active and can occur in depths and current velocities not easily worked with a seine or electrofisher. Because the upper Green River contains habitat similar to that occupied by the species the Elk River, a 95-mile section from Cave Island (Mammoth Cave National Park) to upstream of Greensburg has been designated a critical habitat unit (unoccupied). During 2012-2015, we completed sampling within the critical habitat unit using a benthic trawl at 38 sites and nocturnal sampling with seines and spotlights at six sites. Our objective was to determine if the species still persists in the Green River and document fish community composition, habitat, and water quality variables. We documented a total of 55 species of fish, but the Diamond Darter was not encountered. Updated distributional data were obtained for six state-listed species of conservation concern, as well as a general inventory of the fish fauna and habitat conditions. This information is intended to help guide future Diamond Darter recovery actions (e.g., reintroduction).

Introduction

The Diamond Darter is the second and most recently described member of the genus *Crystallaria* (Welsh and Wood 2008). It is a small, slender perch (maximum size 3 inches [77 mm]) having a somewhat translucent yellow-tan body marked with four wide brown dorsal saddles and 12-14 mid-lateral blotches. The species once had a widespread but spotty distribution the Ohio River basin (Etnier and Starnes 1993), but is now restricted to the lower 37 km (22 mi) of the Elk River, Kanawha County, West Virginia (Welsh et al. 2013, Ruble et al. 2014).

In the Elk River, no Diamond Darter population estimates are available and despite concerted sampling efforts, less than 50 individuals have been collected since it was first discovered there in 1980 (Cincotta and Hoeft 1987, Welsh et al. 2009, Ruble et al. 2014). The species was federally listed as endangered due to its decline and continued threats to its existence (USFWS 2013). Because of its rarity, little is known about the life history and ecology of the Diamond Darter.

In Kentucky, the Diamond Darter is known only from six historic records, three of

which are in the Green River (Table 1). It was last collected in the Green River near Cave Island (now within Mammoth Cave National Park), Edmonson County, in 1929 (Burr and Warren, 1986). Despite extensive sampling for fishes in the middle and upper Green River during the past 30 years, the Diamond Darter has not been reported. However, conventional sampling gears such as seines and electrofishers have not been consistently effective at detecting this species. Furthermore, fish sampling is typically conducted during daytime hours. In the Elk River, sampling at night has proven more effective in capturing the species because of its apparently increased crepuscular and nocturnal activity (Welsh and Wood, 2008; Welsh et al. 2013).

The upper Green River contains patches of habitat similar to that occupied by the Diamond Darter in the Elk River; these include deep riffles, runs, and flowing pools over sand and gravel. A 152.1 km (94.5 mi) section of the Green River from Roachville Ford (River Mile 294.8) to the downstream end of Cave Island (River Mile 200.3) has been designated as a critical habitat unit (CHU) for the Diamond Darter (USFWS 2013). The Green River CHU is being treated as unoccupied, pending a systematic

survey using gear appropriate for capturing the species. This paper summarizes results of an intensive survey (2012-2015) for the Diamond Darter within the Green River CHU.

Methods

The study area includes the section of the mainstem Green River designated as critical habitat for the Diamond Darter (Figure 1). A total of 41 fish sampling sites were selected arbitrarily throughout the CHU based on accessibility, depth, flow, and presence of sand and small gravel substrates. Special emphasis was placed on areas having extensive flowing pools, runs, and deep riffles. These included locations where Shoal Chub (*Macrhybopsis hyostoma*), Streamline Chub (*Erimystax dissimilis*), and Stargazing Minnow (*Phenacobius uranops*) have been collected; species that have habitat preferences similar to those described for the Diamond Darter (Osier 2005, Welsh et al. 2013).

Between 19 September 2012 and 22 September 2015, boat-assisted trawling using an 8' modified trawl (i.e., Mini-Missouri Trawl [Herzog et al. 2005]) was conducted during daylight hours at 38 sites. The trawl

Table 1: Historic collection records for Diamond Darter in Kentucky. UMMZ = University of Michigan Museum of Zoology. USNM = U.S. National Museum of Natural History (Smithsonian Institution). FMNH = Field Museum of Natural History. OSUM = Ohio State University Museum of Zoology.

Locality	Date	Source
Green River, 5 mi SW of Greensburg, Green Co.	7 August 1890	Woolman (1892), UMMZ 197713 (1)
Green River, 0.5 mi E of Greensburg, Green Co.	8 August 1890	Woolman (1892), USNM 63786 (1)
Green River, near Cave Island, Edmonson Co.	31 August 1929	Giovannoli, L., USNM 89467 (2)
Cumberland River, at Kuttawa, Lyon Co.	unknown	FMNH 6825 (1)
Ohio River, near Rising Sun, IN, Boone Co.	1887	Jordan (1899), USNM 39619 (1)
Ohio River, at Russell, Greenup Co.	31 May 1899	OSUM 9688 (1)

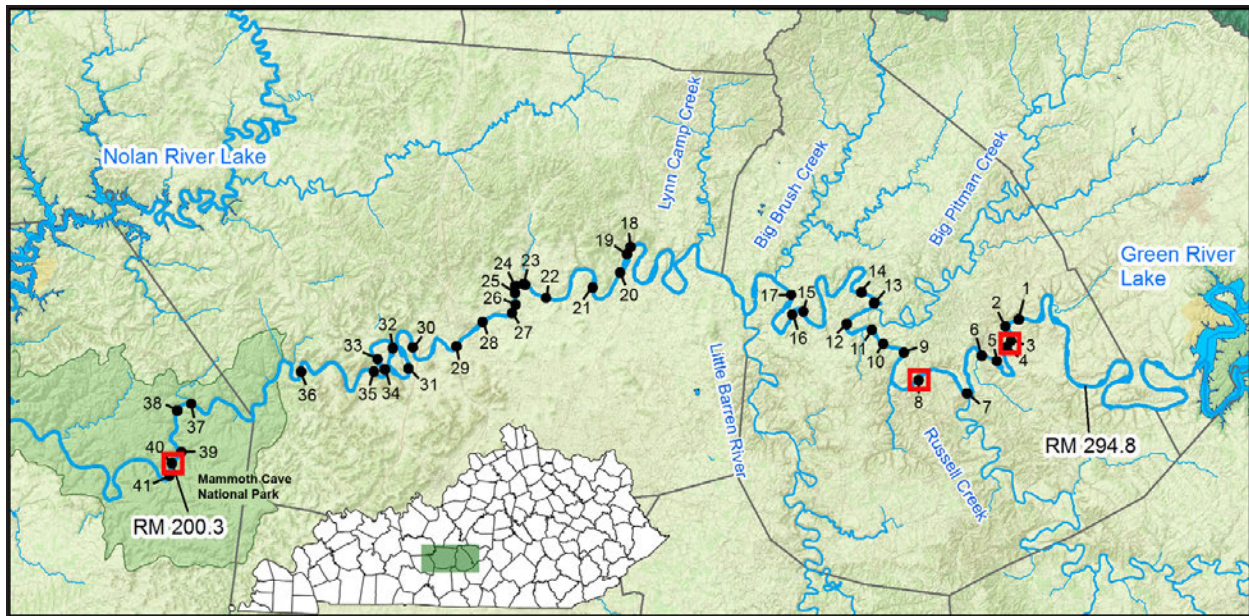


Figure 1: Fish sampling sites in the Green River within the Diamond Darter CHU. Squares = historic localities for Diamond Darter. RM = river mile.

was pulled through pool and riffle/pool transition areas at depths ranging 0.2-2.0 m and current velocities ranging 0.03-1.8 m·s⁻¹. Multiple hauls were performed at each site; the number of hauls per site varied (1-5) depending on the amount of habitat present, stream width and depth, and presence of obstructions (e.g., snags). In addition to trawling, we used a 15' X 6' (1/8" mesh) seine at six sites (1, 6, 7, 20, 36, and 40 [Figure 1]) after dusk (8:30-12:30 p.m.) aided by headlamps and hand-held spotlights. Seining and spotlight searches generally followed methods used in the Elk River by Osier (2005) and Welsh et al. (2013).

Most fish collected were identified on site, enumerated, photo-documented, and released. A limited number of voucher specimens were retained and archived at Kentucky Department of Fish and Wildlife Resources (KDFWR), Frankfort, and the biological collection maintained by Mammoth Cave National Park (MCNP). At each site, stream width, average depth,

current velocity, water temperature, pH, and conductivity were recorded. Substrate composition, riparian zone, and canopy coverage were estimated qualitatively.

Results and Discussion

A total of 106 species of fish have been reported from the mainstem Green River within the Diamond Darter CHU (Table 2). This list is based mostly on vouchered collection records reviewed and compiled by Burr and Warren (1986). We also reviewed and included records from a large volume of post-1986 fish collection data from state and federal agencies, academic institutions and private consultants.

Our sampling effort at 41 sites in the mainstem Green River within the CHU produced 55 fish species representing 12 families (Table 2). Approximately 60% of the species captured were darters (family Percidae, 18 species) and minnows (family Cyprinidae, 15 species). These results demonstrate the effectiveness of the

Missouri trawl in capturing small-bodied, benthic fishes in deeper riverine habitats, as described by Herzog et al. (2005). It did not effectively capture larger species and active swimmers (e.g., pelagic species). Despite our effort to resample historic localities and additional sites with appropriate habitat using specialized gear during day and night, the Diamond Darter was not detected in the CHU.

Most (89%) of the species we captured during our survey are considered occasional to generally distributed and often abundant in suitable habitat. A large portion (43%) of the 106 species known from the CHU are sporadic, several of which are rare and based on fewer than five occurrences. We captured 4 of 11 species within the CHU that have a state conservation status (KSNPC 2012, KDFWR 2013) and 3 of 5 species considered “at-risk” (i.e., have been petitioned for federal listing, USFWS 2012). Occurrence of these species within the CHU is summarized in Table 3.

Conclusions and Recommendations

The Diamond Darter is one of 13 species that may be extirpated from the Green River within the CHU (Table 2). These species have not been collected in the CHU in over 50 years and are known from fewer than five occurrence records. This suggests that they may have been uncommon in the upper Green River historically. Regarding the Diamond Darter in the Green River, Woolman (1892) noted that it was “[n]ot widely distributed, nor common anywhere.” The ability to ascribe Diamond Darter extirpation to potential threats is hampered by insufficient quantification of populations (Grandmaison et al. 2003). Habitat degradation from impoundment, excessive siltation, and stream flow modification are main factors believed to be responsible for the widespread extirpation of Diamond Darter populations and are the main threat to its continued persistence (Welsh et al. 2009). How the large reservoir and series of locks and dams on the Green River have impacted the Diamond Darter is uncertain; however,

Table 3: Occurrences of state-listed and at-risk fish species during 2012-2015 survey within the Green River CHU. Site numbers correspond to map in Figure 1.

Scientific Name	Common Name	Site (number of individuals)
<i>Notropis ariommus</i>	Popeye Shiner	40(6)
<i>Phenacobius uranops</i>	Stargazing Minnow	6(6), 7(6), 19(1), 23(2), 38(2)
<i>Ammocrypta clara</i>	Western Sand Darter	23(12), 27(1), 32(6), 33(1), 35(2), 37(12), 39(11), 40(9), 41(2)
<i>Etheostoma maculatum</i>	Spotted Darter	1(3), 2(1), 3(4), 4(2), 5(1), 7(4), 8(4), 11(7), 12(8), 13(4), 18(5), 21(2), 22(2), 23(117), 25(5), 27(3), 29(6), 30(3), 33(1), 36(1), 38(65), 41(1)
<i>Etheostoma tippecanoe</i>	Tippecanoe Darter	1(4), 3(1), 7(1), 16(2), 17(7), 18(6), 19(10), 21(11), 22(1), 23(22), 25(7), 27(4), 28(11), 30(3), 34(2), 37(2), 38(15), 41(1)
<i>Percina macrocephala</i>	Longhead Darter	7(1), 8(7)

one of the reasons the species may have been able to persist in the Elk River is because it remains largely unimpounded except for a single dam approximately 100 miles upstream of its confluence (Strager 2008).

Sites that appeared most promising for rediscovering the Diamond Darter were near Greensburg (site 6), mouth of Russell Creek (site 7), Sims Bend northeast of Munfordville (site 23), and in MCNP (sites 37-41). These sites offered the best potential in terms of high species richness and habitat diversity, including large expanses of clean sand and gravel. Sites near Greensburg and in MCNP were locations where the species had been collected historically (Table 1). Species with habitat requirements similar to the Diamond Darter such as Streamline Chub and Stargazing Minnow were present in all four areas. The substrate becomes noticeably more sandy from the vicinity of Munfordville downstream, which coincides with the presence of Western Sand Darter.

Protection of existing free-flowing riffle-pool-run habitat in the Green River is highly important to maintain the diverse array of fishes and other aquatic organisms that occur there. This could only serve to benefit the Diamond Darter, if it still exists, and would be necessary for any attempt to re-establish the species in the Green River through captive propagation and reintroduction. The proposed removal of Lock and Dam No. 6 at the western edge of MCNP, if implemented, would restore the natural flow regime to an estimated six miles of the Green River (Stantec Consulting Services, Inc. 2015). Ongoing efforts to restore natural flow and temperature regimes through reoperation of Green River Dam (i.e., Sustainable Rivers Project, Konrad 2010) should be continued in conjunction with long-term biological monitoring.

Acknowledgements

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References

- Burr, B. M. and M. L. Warren. 1986. A distributional atlas of Kentucky fishes. Kentucky Nature Preserves Commission Scientific and Technical Series Number 4. 398 pp.
- Cincotta, D. A. and M. E. Hoeft. 1987. Rediscovery of the Crystal Darter, *Ammocrypta asprella*, in the Ohio River Basin. *Brimleyana* 13:133-136.
- Etnier, D. A. and W. C. Starnes. 1993. The Fishes of Tennessee. University of Tennessee Press, Knoxville.
- Grandmaison, D., J. Mayasich, and D. Etnier. 2003. Crystal darter status assessment report. NRRI Technical Report No. NRRI/TR-2003/19. U.S. Fish and Wildlife Service, Fort Snelling, Minnesota.
- Herzog, D. P., V. A. Barko, J. S. Scheibe, R. A. Hrabik, and D. E. Ostendorf. 2005. Efficacy of a benthic trawl for sampling small-bodied fishes in large river systems. *North American Journal of Fisheries Management*. 25:594-603.
- Kentucky's Comprehensive Wildlife Conservation Strategy. 2013. Kentucky Department of Fish and Wildlife Resources, #1 Sportsman's Lane, Frankfort, KY. <http://fw.ky.gov/kfwis/stwg/> (Date updated 2/5/2013).

- Kentucky State Nature Preserves Commission (KSNPC). 2012. Rare and extirpated biota of Kentucky. (pdf file available at: http://www.naturepreserves.ky.gov/inforesources/reports_pubs.htm).
- Konrad C. P. 2010. Monitoring and evaluation of environmental flow prescriptions for five demonstration sites of the Sustainable Rivers Project. US Geological Survey Open File Report 2010-1065.
- Osier, E. A. 2005. Distribution and habitat use of the crystal darter (*Crystallaria asprella*) and spotted darter (*Etheostoma maculatum*) in the Elk River, West Virginia. Masters Thesis, West Virginia University, Morgantown, WV. 74 pages.
- Ruble, C. L., P. L. Rakes, J. R. Shute, and S. A. Welsh. 2014. Captive propagation, reproductive biology, and early life history of the Diamond Darter (*Crystallaria cincotta*). *American Midland Naturalist* 172:107-118.
- Smith, P. W. 1965. A preliminary annotated list of the lampreys and fishes of Illinois. *Illinois Natural History Survey Biological Notes* 54:1-12.
- Stantec Consulting Services, Inc. 2015. Green River Lock and Dam 6. Dam Removal Feasibility Report. Lexington, Kentucky.
- Strager, J. M. 2008. Diamond darter (*Crystallaria cincotta*) status review – threats assessment data development, final report for U.S. Fish and Wildlife Service, West Virginia Field Office, Elkins, 39 pp. + appendices.
- U.S. Fish and Wildlife Service (USFWS). 2012. Kentucky – Species listed under the Endangered Species Act and pending evaluations of other species. Available online at: <http://www.fws.gov/frankfort/pdf/SpeciesChartKentucky.pdf>
- U.S. Fish and Wildlife Service (USFWS). 2013. Federal register: Endangered and Threatened Wildlife and Plants; Endangered Species Status for Diamond Darter (*Crystallaria cincotta*). Available online at: <https://www.gpo.gov/fdsys/pkg/FR-2013-07-26/html/2013-17938.htm>
- Welsh S. A. and R. M. Wood. 2008. *Crystallaria cincotta*, a new species of darter (Teleostei: Percidae) from the Elk River of the Ohio River drainage, West Virginia. *Zootaxa* 1680:62–68.
- Welsh, S. A., R. M. Wood, and T. L. King. 2009. *Crystallaria cincotta*—Diamond Darter. Page 15 in B. R. Kuhajda, A. L. George, and J. D. Williams. *The Desperate Dozen: Southeastern Freshwater Fishes on the Brink*. Southeastern Fishes Council Proceedings 51:10-30.
- Welsh, S. A., D. M. Smith, and N. D. Taylor. 2013. Microhabitat use of the diamond darter. *Ecology of Freshwater Fish* 22:587-595.
- Woolman A. J. 1892. Report of an examination of the rivers of Kentucky, with lists of the fishes obtained. *Bulletin of the United States Fish Commission* 10:249-288.

Table 2: Fishes recorded from the mainstem Green River within the Diamond Darter CHU during 1890-2015. Species collected in 2012-2015 and number of sites present are indicated. Distribution: G = generally distributed, O = occasional, S = sporadic (from Smith 1965). Kentucky State Nature Preserves Commission (KSNPC) and U.S. Fish and Wildlife Service (USFWS) conservation status: E = endangered, T = threatened, S = special concern, Ex = presumed extirpated, P = petitioned species. * unsubstantiated; needs verification. ** likely extirpated from the CHU.

Scientific Name	Common Name	Distribution in CHU	No. of sites: 2012-2015	Status	
				KSNPC	USFWS
<i>Ichthyomyzon bdellium</i>	Ohio Lamprey	S	2		
<i>Ichthyomyzon greeleyi</i>	Mountain Brook Lamprey	S		T	
<i>Lampetra aepyptera</i>	Least Brook Lamprey	S			
<i>Lampetra appendix</i>	American Brook Lamprey	S		T	
<i>Lepisosteus oculatus</i> *	Spotted Gar *	S			
<i>Lepisosteus osseus</i>	Longnose Gar	O	3		
<i>Amia calva</i> *	Bowfin *	S			
<i>Hiodon tergisus</i>	Mooneye	O			
<i>Anguilla rostrata</i>	American Eel	S			P
<i>Dorosoma cepedianum</i>	Gizzard Shad	G			
<i>Campostoma oligolepis</i>	Largescale Stoneroller	G	15		
<i>Carassius auratus</i> *	Goldfish *	S			
<i>Cyprinella spiloptera</i>	Spotfin Shiner	G	10		
<i>Cyprinella whipplei</i>	Steelcolor Shiner	S			
<i>Cyprinus carpio</i>	Common Carp	O			
<i>Erimystax dissimilis</i>	Streamline Chub	G	20		
<i>Erimystax x- punctatus</i> **	Gravel Chub **	S		Ex	
<i>Hybognathus nuchalis</i> **	Mississippi Silvery Minnow **	S			
<i>Hybopsis amblops</i>	Bigeye Chub	G	15		
<i>Hybopsis amnis</i> **	Pallid Shiner **	S		E	
<i>Hypophthalmichthys molitrix</i>	Silver Carp	S			
<i>Luxilus chrysocephalus</i>	Striped Shiner	G	5		
<i>Lythrurus fasciolaris</i>	Scarlet Shiner	G	1		
<i>Macrhybopsis hyostoma</i>	Shoal Chub	S			
<i>Macrhybopsis storeriana</i> **	Silver Chub **	S			
<i>Nocomis effusus</i>	Redtail Chub	S			
<i>Notemigonus crysoleucas</i>	Golden Shiner	S			
<i>Notropis ariommus</i>	Popeye Shiner	S	1		P
<i>Notropis atherinoides</i>	Emerald Shiner	O	1		
<i>Notropis boops</i> **	Bigeye Shiner **	S			
<i>Notropis buchanani</i>	Ghost Shiner	S			
<i>Notropis micropteryx</i>	Highland Shiner	G	22		

Table 2: Continued

Scientific Name	Common Name	Distribution in CHU	No. of sites: 2012-2015	Status	
				KSNPC	USFWS
<i>Notropis photogenis</i>	Silver Shiner	G	11		
<i>Notropis volucellus</i>	Mimic Shiner	G	22		
<i>Opsopoeodus emiliae</i> **	Pugnose Minnow **	S			
<i>Phenacobius uranops</i>	Stargazing Minnow	O	5	S	
<i>Pimephales notatus</i>	Bluntnose Minnow	G	14		
<i>Pimephales promelas</i> *	Fathead Minnow *	S			
<i>Pimephales vigilax</i>	Bullhead Minnow	O	1		
<i>Semotilus atromaculatus</i>	Creek Chub	S	2		
<i>Carpionodes carpio</i> *	River Carpsucker *	S			
<i>Carpionodes cyprinus</i> *	Quillback *	S			
<i>Carpionodes velifer</i> *	Highfin Carpsucker *	S			
<i>Hypentelium nigricans</i>	Northern Hog Sucker	G	30		
<i>Ictiobus bubalus</i>	Smallmouth Buffalo	O			
<i>Minytrema melanops</i>	Spotted Sucker	O			
<i>Moxostoma anisurum</i>	Silver Redhorse	S			
<i>Moxostoma breviceps</i>	Smallmouth Redhorse	O	2		
<i>Moxostoma carinatum</i>	River Redhorse	O	1		
<i>Moxostoma duquesnei</i>	Black Redhorse	O	4		
<i>Moxostoma erythrurum</i>	Golden Redhorse	G	7		
<i>Ameiurus melas</i>	Black Bullhead	S			
<i>Ameiurus natalis</i>	Yellow Bullhead	S			
<i>Ictalurus punctatus</i>	Channel Catfish	G	12		
<i>Noturus elegans</i>	Elegant Madtom	O	3		
<i>Noturus eleutherus</i>	Mountain Madtom	G	9		
<i>Noturus exilis</i> **	Slender Madtom **	S		E	
<i>Noturus flavus</i> **	Stonecat **	S			
<i>Noturus miurus</i>	Brindled Madtom	G	17		
<i>Noturus nocturnus</i>	Freckled Madtom	S			
<i>Noturus stigmosus</i> **	Northern Madtom **	S		S	
<i>Pylodictis olivaris</i>	Flathead Catfish	O	1		
<i>Esox masquinongy</i>	Muskellunge	S			
<i>Labidesthes sicculus</i>	Brook Silverside	G	3		
<i>Fundulus catenatus</i>	Northern Studfish	G	5		
<i>Fundulus notatus</i>	Blackstripe Topminnow	S			
<i>Gambusia affinis</i>	Western Mosquitofish	G	2		
<i>Cottus carolinae</i>	Banded Sculpin	G	26		
<i>Morone chrysops</i>	White Bass	O			
<i>Ambloplites rupestris</i>	Rock Bass	G	8		
<i>Lepomis cyanellus</i>	Green Sunfish	S			

Table 2: Continued

Scientific Name	Common Name	Distribution in CHU	No. of sites: 2012-2015	Status	
				KSNPC	USFWS
<i>Lepomis gulosus</i>	Warmouth	S			
<i>Lepomis macrochirus</i>	Bluegill	G	1		
<i>Lepomis megalotis</i>	Longear Sunfish	G	11		
<i>Micropterus dolomieu</i>	Smallmouth Bass	G	17		
<i>Micropterus punctulatus</i>	Spotted Bass	G	6		
<i>Micropterus salmoides</i>	Largemouth Bass	G			
<i>Pomoxis annularis</i>	White Crappie	O			
<i>Pomoxis nigromaculatus</i>	Black Crappie	S			
<i>Ammocrypta clara</i>	Western Sand Darter	O	9	E	
<i>Ammocrypta pellucida</i> **	Eastern Sand Darter **	S			
<i>Crystallaria cincotta</i> **	Diamond Darter **	S		Ex	E
<i>Etheostoma bellum</i>	Orangefin Darter	G	28		
<i>Etheostoma blennioides</i>	Greenside Darter	G	25		
<i>Etheostoma caeruleum</i>	Rainbow Darter	G	14		
<i>Etheostoma flabellare</i>	Fantail Darter	O	6		
<i>Etheostoma jimmycarter</i>	Bluegrass Darter	G	29		
<i>Etheostoma kennicotti</i>	Stripetail Darter	O	6		
<i>Etheostoma lawrencei</i>	Headwater Darter	S			
<i>Etheostoma maculatum</i>	Spotted Darter	G	22	T	
<i>Etheostoma nigrum</i>	Johnny Darter	S	1		
<i>Etheostoma rafinesquei</i>	Kentucky Darter	O	1		
<i>Etheostoma tippecanoe</i>	Tippecanoe Darter	G	18		P
<i>Etheostoma zonale</i>	Banded Darter	G	36		
<i>Percina caprodes</i>	Logperch	G	8		
<i>Percina copelandi</i>	Channel Darter	G	17		
<i>Percina evides</i>	Gilt Darter	G	25		
<i>Percina macrocephala</i>	Longhead Darter	S	2	E	P
<i>Percina maculata</i>	Blackside Darter	S	1		
<i>Percina phoxocephala</i>	Slenderhead Darter	O	1		
<i>Percina sciera</i>	Dusky Darter	O			
<i>Percina shumardi</i> **	River Darter **	S			
<i>Percina stictogaster</i> **	Frecklebelly Darter **	S			
<i>Sander canadensis</i>	Sauger	G			
<i>Sander vitreus</i>	Walleye	G			
<i>Aplodinotus grunniens</i>	Freshwater Drum	G	1		
Total species		106	55	11	5

Host-Parasite Associations of Small Mammal Communities: Implications for the Spread of Lyme Disease

Matthew J. Buchholz¹ and Carl W. Dick¹

¹ Department of Biology and Center for Biodiversity Studies, Western Kentucky University

Abstract

Many zoonotic diseases of concern to human and wildlife health are maintained in the environment by small mammal reservoirs and vectored to new hosts by ectoparasitic arthropods. While ecological relationships between small mammals and their ectoparasites are important to these dynamics, this system is poorly understood across much of North America. The goal of this study was to examine relationships between small mammals and ectoparasites across seasons and between different habitat types in South Central Kentucky and potentially provide an ecological explanation for the few human cases of Lyme disease reported in Kentucky. Small mammals were captured using Sherman live traps in three 50x200m trap grids established within Western Kentucky University's Green River Preserve (GRP). Traps were open three consecutive nights each month from November 2014-October 2015. Captured small mammals were identified to species, and standard data such as sex, age, mass, and measurements were recorded. Attached and unattached ectoparasites were removed and retained for identification. A blood sample was collected from each mammal followed by ear tagging for identification of recaptures with subsequent release at the site of capture. Blood was examined for *Borrelia burgdorferi*, the causative agent of Lyme disease in humans, by polymerase chain reaction (PCR). PCR primers used were specific to the *OspA* gene of *B. burgdorferi sensu stricto*. Home range was calculated using the minimum convex polygon method in the program Biotas, and was calculated at the daily level (multiple captures within a given month) and at the lifetime level (multiple captures spanning 2+ months). Population density was calculated using the Schnabel population estimate. Prevalence and mean intensity of ectoparasite species, and prevalence of *B. burgdorferi* DNA in collected blood and tissue, were estimated for and compared between each host species, habitat and season, and age and sex. This study found that the majority of small mammals on the GRP were not infested with ectoparasites, but infestation was affected by age, sex, habitat, and season in different parasite taxa. The study also found few specimens of *Ixodes scapularis*, the primary vector for *B. burgdorferi*, as well as a low prevalence of *B. burgdorferi* compared to Lyme Disease hotspots of New York and Wisconsin. These findings provide the ecological insights into the relative lack of Lyme Disease in Kentucky.

Bird Research at Mammoth Cave National Park: A Synopsis

Brice T. Leech, Jr.¹

¹ Mammoth Cave National Park

Introduction

Mammoth Cave National Park (MACA) has been studying birds and other wildlife, in one aspect or another, since before its inception in 1941. The first recorded bird and mammal survey was conducted in preparation of it becoming a National Park in 1934-5. Next on the record are the Christmas Bird Count (CBC) begun in 1948, the Breeding Bird Survey (BBS) begun in 1995, and the Monitoring Avian Productivity and Survivorship (MAPS) program begun in 2004. In 2011, a bald eagle nest was discovered along the Green River – the first one known to exist in the park’s history. Each of these studies has taught us, and continues to teach us, different things about the birds that the park is charged with preserving and protecting for future generations (Table 1).

The First Survey of Birds and Mammals

Prior to MACA becoming a National Park and as the families were resettling to other locales outside of the park’s boundaries, the Civilian Conservation Corps (CCC) coordinated four camps within the future boundaries of the park. In the transition of home sites and farm fields to a National Park, removal of buildings, fences, and anything family-oriented was essential. The CCC also began planting trees to reforest the landscape. Along with these changes to the landscape an inventory of wildlife was required. Thus, in 1934-35, Claude Hibbard, the pre-park resident wildlife technician, took on the task of conducting the first bird and mammal survey of the area. Through personal field surveys and researching written records, he identified 160 species of birds (6 being extinct or extirpated from the area) and 43 species of mammals (6 being extinct or extirpated from the area) that were, or had been, found within the future boundaries of Mammoth Cave National Park.

Understanding the habitats that Claude was observing while conducting his surveys is

very important. The majority of the park’s landscape was still open farm fields with many roads still connecting family home sites to their neighbors, and some land owners had not completely moved out of the area. The Civilian Conservation Corps (CCC) was also working hard in their reshaping of the look of the landscape. Thus, the expected result would be more prairie and woodland edge species during this time compared to more recent surveys. Of the 160 bird species that Claude found, 41 were not found in the 2005 survey, including the pheasant, ruffed grouse, various pond waterfowl, a number of open-field species, and the now extinct passenger pigeon and Carolina parakeet. Interestingly enough, the wild turkey was labeled extinct in Hibbard’s survey. They are at this time plentiful along the roadways and throughout the park today.

Christmas Bird Count

The Christmas Bird Count in America began on Christmas day 1900, by Frank Chapman with the Audubon Society. Prior to an actual census of birds, hunters took to shooting birds at Christmas time as a holiday tradition called the Christmas “Side

Table 1: Comparison of programs studying birds at Mammoth Cave National Park

Program	Scale	Time Conducted	Duration	What can be Learned
BBS (Breeding Bird Survey)	Large (several miles)	Summer	Long-term	Population numbers Population trends Species diversity
CBC (Christmas Bird Count)	Large (several miles)	Winter	Long-term	Population numbers Population trends Species diversity
MAPS (Monitoring Avian Productivity and Survivorship)	Small (35 acre area)	Summer	Long-term	Individual health Individual reproductivity Individual recruitment Individual returns Species diversity Population survivorship Yearly fluctuations in breeding populations
Individual Surveys	Xtra-Large (park-wide)	Varies	One-time snapshot	Population numbers park-wide Species diversity park-wide

Hunt.” The hunter with the most feathers won. Conservation was in its infancy at this time. Conservation enthusiasts saw the depletion of some bird populations and decided a bird census would be a better idea than the traditional Side Hunt. During the first count in 1900, 27 birders conducted bird counts from Ontario to California, with most of the counts conducted in northeastern North America. The Audubon Society has continued coordinating this count, which takes place between December 14 and January 5 each year, since 1900.

In 1948 Mammoth Cave’s naturalist Henry Lix, Gordon Wilson (from Western Kentucky University fame), and Jimmy Liles began the Christmas Bird Count at Mammoth Cave National Park. The Christmas Bird Count (also known as the Winter Bird Count) has continued practically every year since that year. Western Kentucky University personnel have been coordinating this effort since its inception.

Breeding Bird Survey (BBS)

The Breeding Bird Survey (BBS) was initiated in North America in 1966 by Chandler Robbins, with the USGS Patuxent Wildlife Research Center. It was a response to birds being killed in large numbers and attributed to the increase of pesticide use across the nation (epitomized by Rachel Carson’s *Silent Spring*). The purpose of the BBS is to track the status and trends of bird populations across North America. Today the Canadian Wildlife Service and the National Wildlife Research Center jointly coordinate the BBS program across North America. The BBS is a long-term, large-scale program with over 4100 survey routes conducted during the height of the breeding season across the continental U.S. and Canada.

The BBS was begun around Mammoth Cave National Park in 1995 by private individuals and has continued to the present. The same route is traveled every year during the same period, during the month of June. The

survey consists of driving and walking a 24.5 mile route with stops every half mile.

Eagles are Nesting in the Park!!!!

For many years eagles have been sighted across the park, primarily along the Green and Nolin Rivers. However, until 2011, a nest was never known to exist, despite the number of sightings. Each year since its discovery, a pair of young eaglets have hatched and fledged from the nest, except in 2015. In early March 2015, MACA saw two heavy snows within a week. Prior to the snows, the eagles were sighted sitting on the nest. After the snows the nest was vacant on repeated visits. Ultimately the park had to accept that the nest had failed. In conference with the state of Kentucky's ornithologist, the park found out that several other eagle nests across the state had also failed because of the heavy snows. As of this writing, the MACA eagles are again sitting on the nest with warmer weather in the foreseeable future. The search for more eagle nests is continuing and park employees will continue to monitor the nest for future successes.

Monitoring Avian Productivity and Survivorship (MAPS)

With the observed declines of songbird populations across North America, Dr. David DeSante founded the IBP (Institute for Bird Populations) in 1989 and initiated the MAPS (Monitoring Avian Productivity and Survivorship) program as a continent-wide collaborative attempt to understand why the declines are occurring. This effort coordinates different agencies, groups, and individuals in assisting in the conservation of birds and their habitats through demographic monitoring. Since 1989, more than 1200 MAPS stations encompassing almost every U.S. state and Canadian province have collected more

than 2 million capture records. A related program to understand bird populations is MoSI (Monitoreo de Sobrevivencia Invernal) to study the ecology of Neotropical migrant birds on their wintering grounds.

In 2004, Mammoth Cave National Park employees began a MAPS station in the floodplain of the Green River. This survey is conducted during breeding season and focuses on capturing and banding songbirds (passerines or perching birds). The majority of captures are migratory birds that breed within the park's boundaries, while some of the captures are year-round residents. During the 12 years of banding, we have seen fluctuations in capture numbers; some years more so than others (2010, 2011 and 2015). A heavy rain event is believed to be the cause for the low numbers in 2010, with a delayed recovery in 2012. In 2015, again low numbers occurred and heavy snow storms are believed to be the culprit. Albeit, the actual underlying factors are not completely understood in either of the severe weather episodes. With a continuation of this project and more research into factors influencing count numbers, better management decisions can be made to assist in increasing the numbers of songbirds at Mammoth Cave National Park and across the continent as climate changes occurs and habitat loss increases with more people on the planet.

Watching the Birds Change with the Park

Along with Claude Hibbard's bird survey in 1934-35 (which identified 160 birds), other surveys have continued at various times in the park's history. Two of note are Gordon Wilson (1968) and Mark Monroe (2005). Gordon Wilson, being the consummate ornithologist, conducted a bird survey and found 200 bird species within the park's boundaries. G. Wilson also published

several books on birds in the Mammoth Cave National Park area through the 1950s and 60s. In 2003-2005, another survey was contracted to Mark Monroe in conjunction with the park's inventory and monitoring program. In this survey, 147 bird species were found.

The variation in bird numbers from 160 (in 1935) to 200 (in 1968) to 147 (in 2005) can follow the progression of the park's habitat converting from open farm fields to shrubby young forests to more mature secondary forests as the park's landscape changed during this time. As time passes and the interest in birds continues, additional studies need to be conducted. These surveys can assist the park in management decisions regarding habitat stability, climate change and the human influence of each.

Conclusion

Since its inception Mammoth Cave National Park has carried on scientific studies of all kinds. Many are conducted underground because the park houses most of the longest known cave system in the world. But many

projects are also conducted above ground. MACA receives approximately 500,000 visitors each year. Many of these visitors are young students looking for a place to intrigue their minds, ensnare their interests, to get an idea for a career (or hobby), or to find a way to study what is happening to this earth we live on. It is my hope that when visitors travel to their National Parks during this Centennial year that they will look up, down, and all around them. This will ensure a focus on what is best about our National Parks. The study of birds can be a part in all of these focuses. The more we learn about the world we live on, be it the smallest microbe to the largest tree to the most colorful bird, the better we will be capable of managing this same world.....our home.

LIVE ON BIRDS!!!!

The Effects of Rainfall on Vernal Herbs

Janis LeMaster¹ and Albert J. Meier¹

¹ Western Kentucky University

Abstract

The effects of fire on vernal herbs are little known. David Kem attempted to assess the influences of spring and winter prescribed fires on vernal herbs by collecting abundance data on three sets of research plots located at the Western Kentucky University Green River Preserve in Hart County, KY, on April 9-10, 2010. On April 10, he conducted spring burns, and on February 22, 2011, he conducted winter burns. He then collected post-fire data on the abundance of the herbs on the 12-19 of March, 2011. He found little influence of fire on overall species richness and the density of common species. However, he found changes in abundance of rare species. In spring of 2015, we re-sampled these plots. We found substantial shifts in the abundance of common species, including *Stellaria pubera*, *Dentaria laciniata* and *Erythronium americanum* within sites. It is not clear whether these changes were due to the 2010 and 2011 prescribed fires. Instead we suspect higher amounts of spring rainfall led to these changes.

Oak Regeneration in Mammoth Cave National Park

Bill Moore¹ and Carl Nordman²

¹ NPS Cumberland Piedmont Network

² NatureServe

Abstract

Throughout the eastern United States a growing amount of research is pointing to a change in forest composition. This change, often referred to as mesophication, includes a large increase in the abundance of shade tolerant species such as maple and a concomitant decrease in oak and hickory species. Since 2011 National Park Service ecologists working with NatureServe randomly established 52 forest monitoring plots on Mammoth Cave. While these plots were not established specifically to test this issue of mesophication, they do provide a substantive data set for analysis. Our data indicate that while mesophytic species such as maple and beech comprise only a small proportion of canopy basal area within plots (11% and 4%, respectively), they comprise a much larger proportion of the sapling layer, 29% collectively. In addition, based on a proposed indicator of oak sustainability developed by the U.S. Forest Service, the extent of oak forests on Mammoth Cave may decline in the future.

Conducting a Biological Inventory of Sloan's Crossing Pond

Miranda Thompson¹, Jason A. Matthews¹, and Christy Soldo¹

¹ Murray State University

Abstract

Sloan's Crossing Pond (SCP) is a popular visitor attraction in Mammoth Cave National Park (MCNP). The Civilian Conservation Corps (CCC) constructed the pond by constructing levees around a natural, upland wetland. This pond is unique not only because it is manmade, but also because it holds water year-round unlike most ponds in MCNP. However, in recent years, the pond has begun to fill in with sediment. Our goal was to conduct a biological inventory around SCP and other nearby ponds in order to determine how wildlife utilize these areas and to determine if SCP is unique in the way that wildlife use it. Data on wildlife along with a forest inventory will give us a more complete understanding of the habitats at SCP, Joppa, and Quarry ponds. This information will provide the National Park Service with data that can be used in making science-based decisions about SCP and other ponds in the park. We used trail cameras and audio recording equipment to collect preliminary data on wildlife presence around SCP, Joppa, and Quarry ponds over a several month period. We hope to collect more data in the future, such as, presence of invertebrate species.

Amphibians and Reptiles of Mammoth Cave National Park: What Have We Learned After 13 Years of Monitoring?

John MacGregor¹

¹ Kentucky Department of Fish and Wildlife Resources

Abstract

The documented herpetofauna of Mammoth Cave National Park includes 14 kinds of frogs and toads, 16 salamanders, 8 lizards, 22 snakes, and 9 turtles for a total of 69 species. Inventory and monitoring surveys for amphibians and reptiles have been conducted by the author over the past 13 years (2003-2015). Multiple visits (up to 20 /year) have been made to the park each year. Major techniques used have included the placement and repeated checking of coverboards, the overturning and replacement of natural cover (rocks, logs, leaf litter), targeted searches for amphibians in and near ponds, vernal pools, springs, and streams, road cruising (mostly at night) for snakes, frogs, and salamanders, listening to frog choruses, and various canoe trips and other visual surveys. Most amphibian and reptile species known historically from the park appear to be doing well, and some are even increasing in number. However, at least six reptiles documented from the park during early surveys in the 1930s appear to have been extirpated, undoubtedly due to habitat loss as grasslands, pastures, and open woodlands have largely disappeared during 75 years of fire suppression and uncontrolled reforestation. Amphibians in general have fared better but the eastern tiger salamander seems gone from the park and eastern narrowmouth toads have become quite rare (both also seem to require open habitats). In addition, northern dusky salamanders, abundant at several sites at Mammoth Cave as recently as the mid-1960s, are now known from only two locations even though other semiaquatic salamanders with similar habitat requirements are doing quite well. Looming on the horizon are several newly-discovered amphibian diseases that I believe are responsible for causing major die-offs of frog and salamander eggs and larvae in ponds on the park. At the present time the only way to identify the causative agents is to catch die-offs while they are in progress so proper samples can be collected and tested.

Over a Half Century of Mammoth Cave National Park Mid-Winter Bird Count Data

Blaine Ferrell

Abstract

Mid-winter or Christmas Bird Counts have occurred at Mammoth Cave National Park for over 50 years. Twenty-one species of birds have been observed on almost all counts, 10 species have been observed on only one count and another 20 species have been observed on many counts. Six species observed early during the count period are absent on more recent counts and four species that were not observed on earlier counts now are observed with some frequency. The number of species on count day ranges from 30 to 57 species. Factors that impact the number of species observed on counts such as food availability, number of observers, numbers of parties and weather conditions will be mentioned.

Video Presentation: Monitoring Cave Organisms, Cumberland Piedmont Inventory and Monitoring Network

Kurt Lewis Helf¹, Steven Thomas¹, and Michael Durham²

¹ Cumberland Piedmont Network Inventory & Monitoring Program

² Durmphoto.com

Abstract

The National Park Service's 32 inventory and monitoring networks are charged with collecting, organizing, analyzing, and synthesizing long-term monitoring data of various vital signs in their respective parks. Their goal is to provide park managers with comprehensive, scientifically rigorous data on the status and trends of park resources and enable them to make informed and defensible management decisions. Toward that end, personnel at the Cumberland Piedmont Network are monitoring cave vital signs at four parks in their network. This video demonstrates the methods being used to monitor selected cave organisms (i.e., bats, cave crickets, woodrats, and cave aquatic biota) at these parks by showcasing their efforts at Mammoth Cave National Park. The video features the first known high definition footage of the federally listed endangered species the Kentucky cave shrimp (*Palaemonias ganteri*).

The Activity of *Myotis sodalis* and *Myotis septentrionalis* Changes on the Landscape of Mammoth Cave National Park Following the Arrival of White-nose Syndrome

Rachael E. Griffiths¹, Luke E. Dodd¹, and Michael J. Lacki²

¹ Department of Biological Sciences, Eastern Kentucky University

² Department of Forestry, University of Kentucky

Abstract

White-nose Syndrome (WNS) was detected at Mammoth Cave National Park in January 2013, and population estimates have declined for two federally-listed bat species, *Myotis septentrionalis* (northern long-eared bat) and *Myotis sodalis* (Indiana bat). Presently, there is no evidence for any decline in summer activity of these species across the landscape at the Park. Our objective was to document the annual levels of activity of these species prior to and concurrent with the arrival of WNS. Transects of acoustic detectors (Anabat II) were used to monitor bat activity for 6 years (2010-2015) across a variety of habitats (n = 74 detector locations). Recordings were classified to species level using an automated classifier (Bat Call ID v.2.7c). Classifications were limited to bat passes containing ≥ 5 pulses, and species were identified at the $\geq 95\%$ confidence interval. Our response variables for analyses were the number of passes / night of each species. Using these settings, we recorded a total of 8,478 bat passes (consisting of 101,942 echolocation pulses) over 1,594 detector / nights for the six year period, of which 677 passes (consisting of 5,406 pulses) and 61 passes (consisting of 421 pulses) were classified as *M. septentrionalis* and *M. sodalis*, respectively. Activity of *M. septentrionalis* and *M. sodalis* declined after the detection of WNS ($P < 0.05$). These data indicate a significant change in bat community composition in forested habitats in the Park.

Introduction

White-nose Syndrome (WNS) is a disease associated with the psychrophilic fungus, *Pseudogymnoascus destructans*, and has resulted in the death of more than six million bats (Gargas et al. 2009; Frick et al. 2010; Coleman & Reichard 2014). WNS was discovered during the winter of 2006-2007 in New York and has currently spread to 30 states and 5 Canadian provinces (USFWS 2011; Alves et al. 2014). To date, seven cave hibernating bat species have been confirmed to be affected by WNS (USFWS 2015a). Several *Myotis* species are severely affected by WNS, including the federally listed *Myotis sodalis* (Indiana bat) and *Myotis septentrionalis* (northern long-eared bat).

Myotis sodalis was listed as an endangered species in 1967 (USFWS 2006) and is currently protected under the Endangered Species Act of 1973. Factors contributing to population declines of this species include: habitat destruction, disturbance during hibernation, disease, and predation (USFWS 2006). *M. sodalis* is an insectivore that roosts singly or in maternity colonies during the summer, and hibernates in caves or mines during the winter (Davis 1974; Thomson 1982). Since *M. sodalis* has been listed as an endangered species for many years, a prodigious amount of research has been focused on its recovery and monitoring. Past recovery efforts for *M. sodalis* have largely concentrated on preventing habitat

destruction and human disturbance during hibernation (USFWS 2006). WNS poses a different threat to the survival of this species due to limited knowledge of the causal effects of the fungus, and the difficulty of preventing the spread of the disease. The effect of WNS on populations of *M. sodalis* has been well documented through hibernaculum counts and summer surveys. Population estimates for *M. sodalis* fell from 635,349 individuals in 2007 to 523,636 individuals in 2015 (USFWS 2015b). While the decline of *M. sodalis* has been well-documented, less sound estimates exist for some species, including *M. septentrionalis*.

Myotis septentrionalis was listed as a federally-threatened species in April 2015 (USFWS 2015c). WNS has spread across 60% of the distribution of *M. septentrionalis*, and has resulted in unprecedented declines for this once common species (USFWS 2015c). *M. septentrionalis* is an insectivore that roosts in live or dead trees during the summer, either singly or in maternity colonies (Caceres & Barclay 2000; Reid 2006). This species is not a colonial hibernator. Instead it hibernates singly in crevices or cracks of cave walls (Davis 1974). *M. septentrionalis* are often overlooked during hibernaculum counts, rendering accurate population estimates difficult to achieve (Steve Thomas, pers. comm.). Populations of this species were thought to be stable until the arrival of WNS; now this disease poses a serious threat to the persistence of *M. septentrionalis* (Coleman & Reichard 2014; USFWS 2015c).

WNS has continued to spread across North America, and threatens *M. sodalis* and *M. septentrionalis* across the majority of their distributions. Hibernaculum counts have confirmed population declines of both species in winter (Coleman & Reichard

2014), but the presumed decline of these populations across Kentucky's landscape in summer remains largely undocumented. We had a unique opportunity to compare bat activity prior to and following detection of WNS at Mammoth Cave National Park (MACA). Our objective was to determine the effect of WNS on the activity of these *Myotis* species across the landscape. We hypothesized there would be a decrease in activity of *M. septentrionalis* and *M. sodalis* across the landscape of the Park following the detection of WNS.

Methods

Mammoth Cave National Park is a 23,000-ha parcel of land located in portions of Barren, Edmonson, and Hart counties on the edge of the Crawford-Mammoth Cave Uplands of the Interior Plateau of Kentucky (Woods et al. 2002). MACA has extensive limestone cave systems, in which *M. sodalis* and *M. septentrionalis* are known to hibernate (NPS 2012; Lacki et al. 2015). The first detection of WNS in Kentucky was in Trigg County during the winter of 2011-2012 (Hines & Armstrong 2014). In response to this, MACA implemented its own WNS management plan (NPS 2012), and WNS was detected in the Park in January 2013 (NPS 2013).

We monitored bat activity prior to detection of WNS (2010-2012) and after detection of WNS (2013 – 2015). Bat activity was assessed from April-September each year using Anabat II acoustic detectors (Titley Electronics, Colombia, MO). Detectors were housed in plastic protective cases and powered with external batteries, with microphones deployed 1.5-m above ground (Dodd et al. 2013). Acoustic surveys spanned multiple consecutive nights to account for nightly variation throughout the growing season. Detectors were deployed at

randomly established transect sites across a variety of habitats at MACA (n = 74 detector locations) and regularly calibrated (Fig. 1) (Dodd et al. 2013).

We used Kaleidoscope v.1.2 (Wildlife Acoustics, Maynard, MA) to download acoustic data (zero-crossing format) collected from sunset to sunrise during our surveys. We used an automated program (Bat Call ID v.2.7c) to classify recorded bat passes according to phonic group and species. Bat passes containing ≥ 5 pulses were assigned classifications. Classification of the *Myotis* phonic group and species were conducted at $\geq 70\%$ and $\geq 95\%$ confidence levels, respectively. Our subsequent response variables were the number of passes per detector / night for the *Myotis* phonic group, *M. septentrionalis*, and *M. sodalis*; these variables were considered in relation to WNS arrival to the Park (pre-detection vs. post-detection). We did so using the program 'R' v.3.1.2 (R Development Core Team 2012) and performed Student's t-tests.

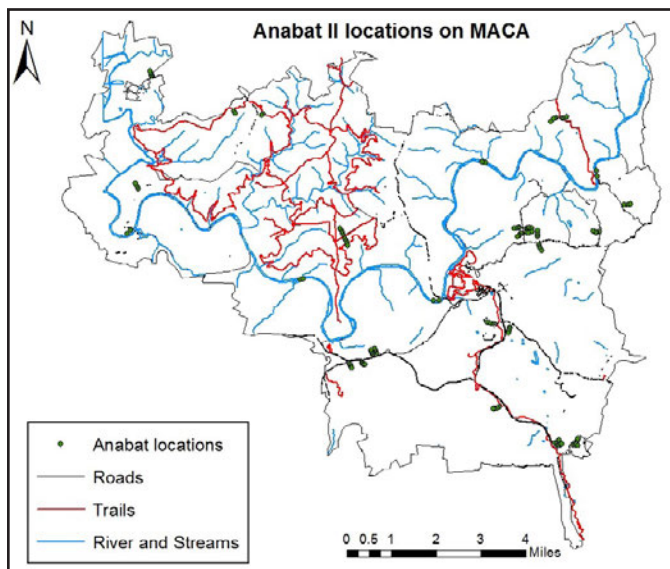


Figure 1: A map of Mammoth Cave National Park, including acoustic detector (Anabat II) locations (n = 74) used for bat activity monitoring from 2010 - 2015.

Results

We recorded a total of 8,478 bat passes (consisting of 101,942 echolocation pulses) over 1,594 detector / nights across all years. For *M. septentrionalis*, 677 passes (consisting of 5,406 pulses) were recorded before the detection of WNS and no pass was recorded after the detection of WNS. For *M. sodalis*, 60 passes (consisting of 416 pulses) were recorded before the detection of WNS and only a single pass (consisting of 5 pulses) was recorded after the detection of WNS. The number of passes classified as the *Myotis* phonic group decreased from 3,867 passes (consisting of 44,604 pulses) before the detection of WNS to 70 passes (consisting of 755 pulses) after the detection of WNS. Analyses demonstrated the number of bat passes per detector / night classified as the *Myotis* phonic group, *M. septentrionalis*, and *M. sodalis*, all decreased significantly following arrival of WNS ($P < 0.01$, Table 1, Fig. 2).

Discussion

Since the detection of WNS, activity of *M. septentrionalis*, *M. sodalis*, and the *Myotis* phonic group have significantly declined across the forested landscape at MACA. Though we observed a decline in activity after the detection of WNS, some of this change could be a result of recorded bat passes being incorrectly classified. However, given the extent of change observed, it is more likely that the declines in *Myotis* activity were due to the impacts of WNS on this genera as a whole. WNS produces mortality in affected bat species by increasing arousal times from torpor, leading to dehydration and depletion of fat reserves, resulting in death of infected bats (Reeder et al. 2012; Willis et al. 2011). WNS has increased the levels of overwinter mortality of these species in MACA, resulting in declines in winter

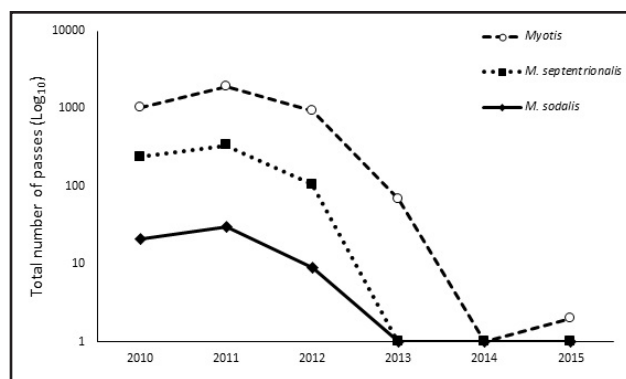


Figure 2: Trends in *Myotis* activity (bat passes / year) at Mammoth Cave National Park from 2010-2015, as classified using BCID. White-nose syndrome was detected in the park in January of 2013.

populations (Thomas 2016). These species are primary predators of nocturnal insects (Davis 1974), and their recent declines could lead to adverse effects throughout the entire Park ecosystem (Boyles et al. 2011).

Our findings at MACA are consistent with acoustic surveys conducted before and after the detection of WNS in other localities (Coleman et al. 2014; Dzal et al. 2011). WNS can have an indirect impact on bat species which are not susceptible to WNS infection. The decline of *Myotis* species can potentially alter niche partitioning of bat species within a forest community (Jachowski et al. 2014), with bat species not affected by WNS expanding their use of habitats previously

occupied by WNS impacted species. Decreasing populations of *Myotis* species could potentially increase the amount of resources available to other bat species through reduced levels of competition.

Through acoustic monitoring, we have recorded declines in activity of two federally-listed bat species concurrent with the detection of WNS in MACA. Winter counts in hibernacula have documented the decline of other *Myotis* species in the Park as well (Thomas 2016). Further acoustic monitoring, mist netting, and harp trapping surveys are needed to provide additional data on the persistence of bat populations in the Park.

Acknowledgements

We thank our coinvestigators, including M. Dickinson, L. Rieske-Kinney, N. Skowronski, S. Thomas, and R. Toomey. We are grateful for their assistance and suggestions. The authors also thank T. Culbertson, S. James, K. Rose, and J. Winters for technical support. We are indebted to S. Fulton, M. Thalken, and S. Trimboli for their assistance. Finally, we are grateful to the staff of Mammoth Cave National Park for continuing support. This research was supported by grants from the USDA Joint Fire Sciences Program (#10-1-06-1 and #14-1-05-22).

Table 1: Mean \pm SE passes per detector / night of the *Myotis* phonic group, *Myotis septentrionalis*, and *Myotis sodalis* at Mammoth Cave National Park prior to detection of White-nose syndrome (pre-WNS) (2010 – 2012) and following detection of White-nose Syndrome (post-WNS) (2013 – 2015).

	Mean \pm SE Passes / Detector-Night		
Response Variable	Pre-WNS	Post-WNS	Test Significance
<i>Myotis</i> phonic group	3.4 \pm 0.3	0.27 \pm 0.11	t 1,344 = 9.6, P < 0.01
<i>Myotis septentrionalis</i>	0.60 \pm 0.09	0 \pm 0	t 1,134 = 6.8, P < 0.01
<i>Myotis sodalis</i>	0.05 \pm 0.01	0.004 \pm 0.004	t 1,379 = 4.9, P < 0.01

Literature Cited

- Alves, D. M. C. C., L. C. Terribile, & D. Brito. 2014. The potential impact of white-nose syndrome on the conservation status of north american bats. *PloS one*, 9, e107395.
- Boyles, J. G., P. M. Cryan, G. F. McCracken, T. K. Kunz. 2011. Economic importance of bats in agriculture. *Science* 332: 41–42. <http://doi.org/10.1126/science.1201366>.
- Caceres, M. C. & R. M. R. Barclay. 2000. *Myotis septentrionalis*. *Mammalian Species*, 1–4.
- Coleman, J. T. H. & J. D. Reichard. 2014. Bat White-nose Syndrome in 2014: A Brief Assessment Seven Years after Discovery of a Virulent Fungal Pathogen in North America. *Outlooks on Pest management*, 25: 374–377.
- Coleman, L. S., W. M. Ford, C. A. Dobony, & E. R. Britzke. 2014. A Comparison of Passive and Active Acoustic Sampling for a Bat Community Impacted by White-nose Syndrome. *Journal of Fish and Wildlife Management*, 5(1): 1–24. <http://doi.org/10.3996/082103-JFWM-057>.
- Davis, W. H. 1974. *Mammals of Kentucky*. University Press of Kentucky, Lexington, KY.
- Dodd, L. E., N. S. Skowronski, M. B. Dickinson, M. J. Lacki, and L. K. Rieske. 2013. Using LiDAR to link forest canopy structure with bat activity and insect occurrence: preliminary findings. Pp. 50-57 in *Proceedings of Mammoth Cave National Park's 10th Research Symposium* (S. R. Trimboli, editor). Mammoth Cave National Park, Mammoth Cave, Kentucky.
- Dzal, Y., L. P. McGuire, N. Veselka, & M. B. Fenton. 2011. Going, going, gone: the impact of white-nose syndrome on the summer activity of the little brown bat (*Myotis lucifugus*). *Biology Letters*, 7(3): 392–4. <http://doi.org/10.1098/rsbl.2010.0859>.
- Frick, W. F., J. F. Pollock, A. C. Hicks, K. E. Langwig, D. S. Reynolds, G. G. Turner, C. M. Butchkoski, & T. H. Kunz. 2010. An Emerging Disease Causes Regional Population Collapse of a Common North American Bat Species. *Science*, 329: 679–682.
- Gargas, A., M. T. Trest, M. Christensen, T. J. Volk, & D. S. Blehert. 2009. *Geomyces destructans* sp. nov. associated with bat white-nose syndrome. *Mycotaxon*, 108: 147–154.
- Hines, B. & M. Armstrong. 2014. Kentucky WNS Response Plan Updated January 2014.
- Jachowski, D. S., C. A. Dobony, L. S. Coleman, W. M. Ford, E. R. Britzke, & J. L. Rodrigue. 2014. Disease and community structure: white-nose syndrome alters spatial and temporal niche partitioning in sympatric bat species. *Diversity and Distributions*, 20(9): 1002-1015. <http://doi.org/10.1111/ddi.12192>.
- Lacki, M. J., L. E. Dodd, R. S. Toomey, S. C. Thomas, Z. L. Couch, & B. S. Nichols. 2015. Temporal changes in body mass and body condition of cave-hibernating bats during staging and swarming. *Journal of Fish and Wildlife Management*, 6: 360–370.
- National Park Service (NPS). 2012. White-Nose Syndrome Response Plan. https://www.whitenosesyndrome.org/sites/default/files/http___www.nps_.gov_maca_parkmgmt_loader.pdf. Accessed December 1, 2015.
- National Park Service (NPS). 2013. Mammoth Cave National Park News Release: White-Nose Syndrome Confirmed in Park Bats [Press release]. Retrieved

from https://www.whitenosesyndrome.org/sites/default/files/files/nr_-_maca_wns_announcement_-_final.pdf. Accessed February 2, 2016.

R Development Core Team. 2012. R: A Language and Environment for Statistical Computing. R Foundations for Statistical Computing Vienna, Austria.

Reeder, D. M., C. L. Frank, G. G. Turner, C. U. Meteyer, A. Kurta, E. R. Britzke, ... D. S. Blehert. 2012. Frequent Arousal from Hibernation Linked to Severity of Infection and Mortality in Bats with White-Nose Syndrome. *PLoS ONE*, 7(6): e38920. <http://doi.org/10.1371/journal.pone.0038920>.

Reid, F. A. 2006. Peterson Field Guide to Mammals of North America, Fourth. Houghton Mifflin Company, New York.

Thomas, S. C. 2016. Recent winter bat numbers at Mammoth Cave National Park: Pre/Post white-nose syndrome arrival. Poster presented at: Southeastern Bat Diversity Network. 21st Annual Meeting and 26th Annual Colloquium on the Conservation of Mammals in Southeastern U.S. Feb 18-19; Lake Guntersville State Park, AL.

Thomson, C. E. 1982. *Myotis sodalis*. *Mammalian Species*, 1–5.

U.S. Fish and Wildlife Service (USFWS). 2015a. White-Nose Syndrome: The Devasting Disease of Hibernating Bats in North America. <http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1457&context=usfwspubs>. Accessed January 2016.

U.S. Fish and Wildlife Service (USFWS). 2015b. Table 1. 2015 Population estimates for the Indiana bat (*Myotis sodalis*) by USFWS Region. US Fish and Wildlife Service, Bloomington, IN, Ecological Services Field Office.

U.S. Fish and Wildlife Service (USFWS). 2015c. Endangered and threatened wildlife and plants; threatened species status for the northern long-eared bat with 4(d) Rule. 50 CFR Part 17. *Federal Register*, 80, 1–61.

U.S. Fish and Wildlife Service (USFWS). 2011. A national plan for assisting States, federal agencies, and tribes in managing white-nose syndrome in bats. US Fish and Wildlife Service, Hadley, MA, 253.

U.S. Fish and Wildlife Service (USFWS). 2006. Indiana bat (*Myotis sodalis*) draft recovery plan: first revision. US Fish and Wildlife Service, Fort Snelling, MN, 237.

Willis, C. K. R., A. K. Menzies, J. G. Boyles, & M. S. Wojciechowski. 2011. Evaporative water loss is a plausible explanation for mortality of bats from white-nose syndrome. In *Integrative and Comparative Biology*, 51: 364–373. <http://doi.org/10.1093/icb/ucr076>.

Woods, A. J., J. M. Omernik, W. H. Martin, G. J. Pond, W. M. Andrews, S. M. Call, J. A. Comstock, and D. D. Taylor. 2002. Ecoregions of Kentucky (color poster with map, descriptive text, summary tables, and photographs): Reston, VA., U.S. Geological Survey (map scale 1:1,000,000).

Recent Winter Bat Numbers at Mammoth Cave National Park: Pre/Post White-Nose Syndrome Arrival

Steven Thomas¹

¹ Cumberland Piedmont Network Inventory & Monitoring Program

Abstract

Eight of 13 bat species found at Mammoth Cave National Park regularly roost in caves at some time of the year. Three species that inhabit park caves are federally listed: gray bat (*Myotis grisescens*), Indiana bat (*M. sodalis*), and northern long-eared bat (*M. septentrionalis*). Regular population monitoring of hibernating bats to determine trends in winter bat abundance has occurred in a few park caves since the early 1980s. Since 2007, biennial winter bat counts in selected park caves have included the use of digital photography. White-nose syndrome (WNS) was first confirmed in the park in early January 2013. This disease has been documented (somewhere) in seven of the eight cave-dwelling bat species that occur on the park. The fungus which causes the disease has been found on the eighth species [Rafinesque's big-eared bat (*Corynorhinus rafinesquii*)], but without confirmation of the disease. Results from five winter bat counts at three caves between 2007 and 2015 (3 counts pre-WNS, 2 counts post-WNS), showed increasing numbers for the gray bat and big brown bat (*Eptesicus fuscus*), and decreasing numbers for the little brown bat (*M. lucifugus*), the tri-colored bat (*Perimyotis subflavus*) and the Indiana bat over the 9-year period. Bat numbers for four species decreased during the brief post-WNS period (from 2013 to 2015): big brown bat (35.7% decrease), Indiana bat (39.0%), tri-colored bat (62.7%), and little brown bat (92.1%). Results from five winter bat counts at five caves used by the Rafinesque's big-eared bat between 2008 and 2016 (3 pre-WNS, 2 post-WNS), showed increasing numbers for this species over the entire 9-year period. Although the declines observed during the post-WNS period are not necessarily a direct result of WNS, these findings are similar to results reported elsewhere in the eastern United States during the first few years following arrival of the disease.

Summary of 2015 Winter Bat Monitoring at Mammoth Cave National Park

Laura Shultz¹, Chris Clark¹, Rickard Toomey², Shannon Trimboli³

¹ Student Conservation Association, Mammoth Cave National Park

² Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park

³ Mammoth Cave International Center for Science and Learning, Ogden College of Science and Engineering, Western Kentucky University

Abstract

Mammoth Cave National Park is home to thirteen species of bats, seven of which are afflicted by White Nose Syndrome (WNS), a disease devastating bat populations in the northeastern United States and eastern Canada. In an intensive monitoring effort driven by public health concerns, transect and entrance observations were carried out daily throughout the winter of 2015 along visitor use areas.

This monitoring captured trends in the observable bat population on all routes – the numbers would increase, peak in late February/early March, and then decline. We believe that this is due to the aberrant behaviors exhibited by bats afflicted with White Nose Syndrome. As the winter progresses, tri-colored bats are moving out of their normal hibernation sites into entrances and cold areas where they are observed along the monitored transects. After early March, the bat numbers decline.

While we did not see flying bats during the day in our entrance observations, 12% of dead bats collected throughout the winter season were collected from the surface. Flying bats were often documented within the cave, with a large portion reported from the Domes and Dripstones route despite it housing considerably fewer bats. The Domes and Dripstones route is also where the majority of bat-human contacts have occurred and looking into this discrepancy in activity levels compared to bat numbers observed is an opportunity for further research.

Dead bats collected throughout the winter season were analyzed for both rabies and WNS. Out of 75 submissions, none tested positive for rabies. While the analysis for WNS is still occurring, it appears likely that they will all test positive. Mammoth Cave National Park is the first year-round NPS show cave to contend with this disease; this presents an amazing opportunity to gain knowledge on this disease and spread the lessons learned to other land managers. While we have learned a lot from this intensive monitoring, it has also opened up more avenues of inquiry.

Introduction

Mammoth Cave National Park is home to nine different species of cave bats and four species of tree bats. Out of the ten species that utilize the caves within the park to hibernate, mate, and raise their young, seven are affected by a new disease that has been devastating bat populations across the northeastern United States and eastern Canada: White Nose Syndrome. Through traditional park monitoring in association with the Cumberland Piedmont Network

(see S. Thomas paper in this volume), up to an 80% loss in four of the seven affected species has been documented as of 2015. This sets a grim stage for understanding WNS-influenced bat behavior within the National Park Service.

The presence of WNS was first confirmed in Mammoth Cave, KY in January 2013 at colonial *Myotis* sites (Carson 2013). It was found along several cave routes and entrances the following year which are used to accommodate over 400,000 visitors annually who venture into the longest cave in the world. This year-round usage places Mammoth Cave in a unique position to investigate the effects of WNS on bat populations and tour operations.

As the first year-round show cave in the National Park Service to contend with this disease, Mammoth Cave is acting as a leader in the management of WNS, the bat populations it affects, and the visitors coming to experience their national park. The lessons and investigations done here can serve as a tool for other land managers as they formulate management plans for their own sites.

Background

As bats hibernate and are affected by WNS, they exhibit several aberrant behaviors such as moving into colder areas by cave entrances, increased activity such as flying in the cave or on the landscape even in the day or mid-winter, decreased responsiveness to human disturbance, and death (Coleman 2011). At Mammoth Cave National Park, in addition to the biological concerns, the aberrant behavior that garnered the most attention from a public health perspective is the increased activity. Would WNS affected bats flying along the toured routes put visitors at an increased risk of bat-human contacts and rabies exposure?

Bats with WNS, having large open wounds, are not able to control their flight and behave erratically – symptoms that mirror bats with the rabies virus. In 2014, Mammoth Cave had 11 bat-human contacts occur. While this is a very small percentage of the over 410,000 visitors, researchers, and employees that utilize the cave, the park evaluated the situation diligently. In December 2014, an NPS Disease Outbreak Investigation Team composed of experts across fields including veterinary medicine, wildlife, public health, and epidemiology met to evaluate the situation (Wong 2015).

As part of their investigation and final report, daily monitoring was implemented along toured routes to understand bat behavior and see if there were any identifiable predictors for bat-human contacts. Park operations and the public health components of the work dictated many of the monitoring choices. The areas to be given the highest priority in monitoring corresponded with the Division of Interpretation's tour schedule and areas of visitor use: the Historic Route, Domes and Dripstones Route, Carmichael Entrance Decline, Great Onyx Cave, and caves near high density surface locations like picnic areas or the Visitor Center.

The Historic section of Mammoth Cave has three to four separate tours offered during the winter monitoring season. These tours include the Historic, Mammoth Passage and Discovery Self-Guided tours. By late spring, Gothic Avenue is added. These tours have lengths that range from three-quarters of a mile to two miles in length, with in cave-times ranging from one hour to one hour and forty-five minutes.

Another highly visited area is the New Entrance to Mammoth Cave section. Tours that utilize this area include Domes and

Dripstones, Frozen Niagara, portions of the Introduction to Caving, and portions of the Wild Cave tour. The New Entrance section has man-made entrance and exit points that include loosely sealed bunker style entrances with one inch access holes included for wildlife use. This allows bats to enter and utilize these areas. These tours have a walking length ranging from one-quarter of a mile up to one mile.

The Carmichael Entrance Decline consists of 183 stairs along a two hundred and twenty foot blasted entrance way. This is utilized by the Wild Cave tour on weekends. Great Onyx Cave covers one mile and is occasionally utilized by the Park's Environmental Education program to conduct school field trips. Dixon Cave is un-toured and is primarily a hibernacula for Gray Bats (*Myotis grisescens*) and Indiana Bats (*Myotis sodalis*), but other bat species can be found within the cave during winter as well. Dixon Cave is within two tenths of a mile from the Historic Entrance, within one hundred yards of the picnic area, and is situated along a major surface trail route behind the Visitor Center.

Methods and Materials

During the winter monitoring season of 2015, running from January 1 to May 1, 2015, bat monitoring consisted of two main activities: bat transects and surface tier 3 observations.

Bat transects were conducted along the Historic Route (daily), Domes and Dripstones Route (three times/week), and the Carmichael Entrance Decline (weekly). These observations included conducting a bat census (counting and identifying roosting bats along the route); noting active bats, flying bats, and bats with visible fungus; and logging dead bats and collecting them for testing if possible. Active bats and

bats with visible fungus were counted as a subset of presumed alive bats. This means that on the data sheet, bats that were alive and had visible fungus or were active would be tallied once in each category. In the same manner, collected dead bats were tallied as a subset of dead bats observed. Collected bats were sent to the Biological Resource Division of the National Park Service in conjunction with Colorado State University Testing Lab, for rabies and White Nose Syndrome analysis.

Each route was divided into sections based on environmental conditions for ease of monitoring and to assess bat utilization of various cave areas. The Historic Route was split into 11 sections; Domes and Dripstones into 12 sections; Carmichael into 6 sections and Violet City Entrance (not toured, but assessed due to ease of access and proximity to the Carmichael Entrance Decline). All observations in each section were made using minimal gear: a bright cave light, clipboard, datasheet, pencil, and proper PPE including a cave helmet, backup light, and leather and nitrile gloves. Ziploc bags, a sharpie, and a ruler were also used in the collection and processing of dead bats.

Surface tier 3 observations were also conducted at Dixon Cave daily according to protocols established in the 2011 White Nose Syndrome Management Plan. These observations consisted of standing at the entrance and visibly observing any bat activity. Data collected during these observations include: number of bats flying, number of bats observed per minute, surface temperature using a digital thermometer, temperature to the cave from the observation area using an infrared thermometer, and weather conditions.

Once a week, recorders would perform a 'gate check.' These involved looking for bats

moving towards the entrance, bats roosting outside the cave gate, and dead or moribund bats. Other data collected included cave air flow (inhaling/exhaling/stagnant) and any unlawful human disturbance. Gate checks were conducted with equipment similar to that used for transects.

Opportunistic data, looking at bat activity, was also collected in cooperation with other park staff (mainly interpreters). They were asked to note any flying bats that may have occurred during their cave tours and in what section of the cave they were observed. In both our main transect data and these more opportunistic observations, if a flying bat left your field of vision and subsequently re-entered your view, it was tallied as a separate bat.

Data and Discussion

Bats counted in each transect along the routes increased from the beginning of winter, peaked in late February or early March, and fell until the end of observations on May 1, 2015. This holds true for all three routes, despite having various entrance types (natural versus artificial) and significantly different bat numbers overall.

The Domes and Dripstones route peaked at 17 bats on Feb. 24, 2015; the Carmichael Entrance Decline held 31 bats at its peak on Feb. 27, 2015; and Historic, which held the highest number of hibernating bats, peaked at 118 bats on Mar. 14, 2015. While the lowest counts on the Domes and Dripstones route and the Carmichael Entrance Decline resulted in no bats observed along the route, in the Historic section there were always bats present along the route with the lowest set of observations tallying 7 bats. These bell-curve shaped trends are shown in Figures 1 - 3 for the Historic Section, Domes and Dripstones route, and Carmichael Entrance Decline respectively.

This trend is clearly tied to the tri-colored bat (*Perimyotis subflavus*). While the numbers of big brown bats (*Eptesicus fuscus*) and *Myotis* bats both peaked at 17, the numbers of tri-colored bats peaked at 85. The higher quantity of tri-colored bats contributed to their ability to form the trend. In addition, while the *Myotis* bats exhibit a similar trend, but peaking earlier (on Feb.27, 2015), the number of big brown bats fluctuates more irregularly, as can be seen best in Figure 1. The main trend, driven by the tri-colored bat, is interpreted to reflect the characteristics of this particular species and aberrant behaviors due to White Nose Syndrome.

The tri-colored bat is a species that hibernates singly. Because of their roosting behavior, it is hard to get an accurate population count on this species. Prior to WNS they were typically spread throughout the warmer regions of the caves where temperatures are between 8-14 °C (46-57 °F). They are one of the species hit the hardest by WNS. Because they were so common before the onset of WNS, there is no record of attempts to even document the levels of tri-colored bats throughout their range.

As the winter progresses, WNS afflicted tri-colored bats are moving towards the entrance into unusually cold areas of the cave, an aberrant behavior resulting from disease. This behavior is the most likely factor driving the trend observed along all three routes. As more bats are afflicted and begin to exhibit symptoms, they are coming out of the more obscure warm areas of the cave and increasing in density by entrances and along tourist routes where the observations occurred.

The subsequent decreasing trend in bats observed could be due to WNS mortality.

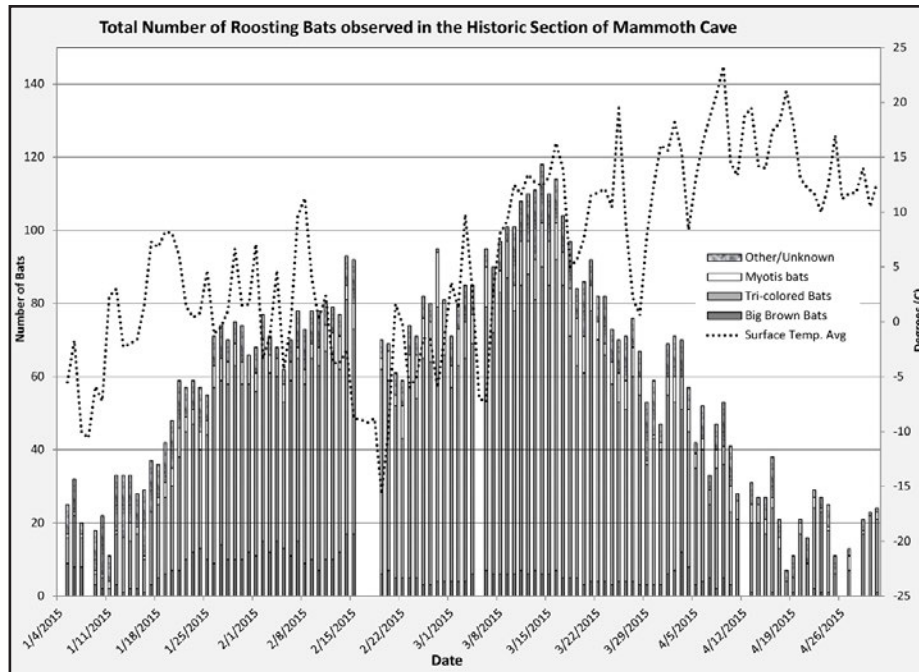


Figure 1: This graph depicts the number of bats presumed alive that were observed along the Historic Section of Mammoth Cave transect in 2015 split by species according to the date. The average surface temperature is also plotted as an indicator of climactic conditions.

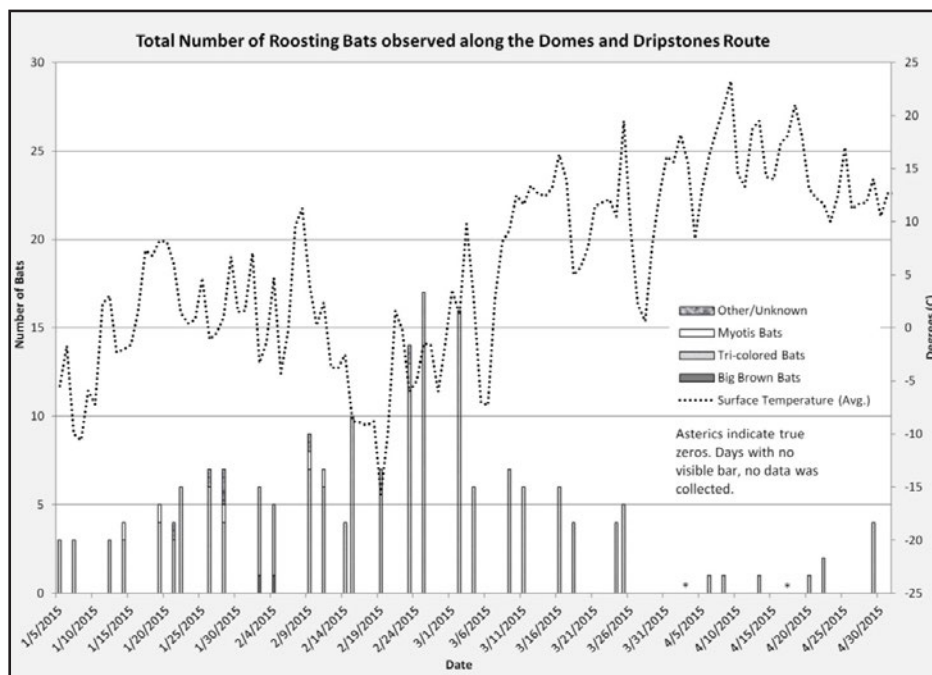


Figure 2: This graph depicts the number of bats presumed alive that were observed along the Domes and Dripstones route transect in 2015 split by species according to the date. The average surface temperature is also plotted as an indicator of climactic conditions.

We collected 75 dead bats from all sources over the course of our monitoring, and an additional unknown number could have exited the cave and died on the landscape, died in an area of the cave where they were not visible, or been consumed.

While death on the landscape is well documented in other parks, it has been observed with less frequency at Mammoth Cave National Park. The surface tier 3 Observations conducted at Dixon Cave yielded no unusual flying bat activity except for one isolated day.

On this day we saw four flying bats, but we had also concluded the biennial population count at Long Cave, approximately 4.5 miles away, an hour previous to the Dixon Cave observations. As both of these caves harbor the same species and are in close proximity, it is a logical conclusion that the flying bat

observations in this case were due to human disturbance at Long Cave rather than due to WNS aberrant behavior. Flying bats were not observed on any other day in the 2015 season.

Despite the absence of aberrant flying behavior in our tier 3 observations, we do see isolated incidents of dead or moribund bats being found on the landscape and called in to the Science and Resource Management Division for recovery. Out of the 75 dead bats collected throughout our observations, 9 (12%) were from parking lots or other high visitor use areas across the landscape of Mammoth Cave National Park. This discrepancy presents an opportunity for further research.

Though in our formal tier 3 observations we did not see flying bats, there is a fair level of activity occurring throughout the

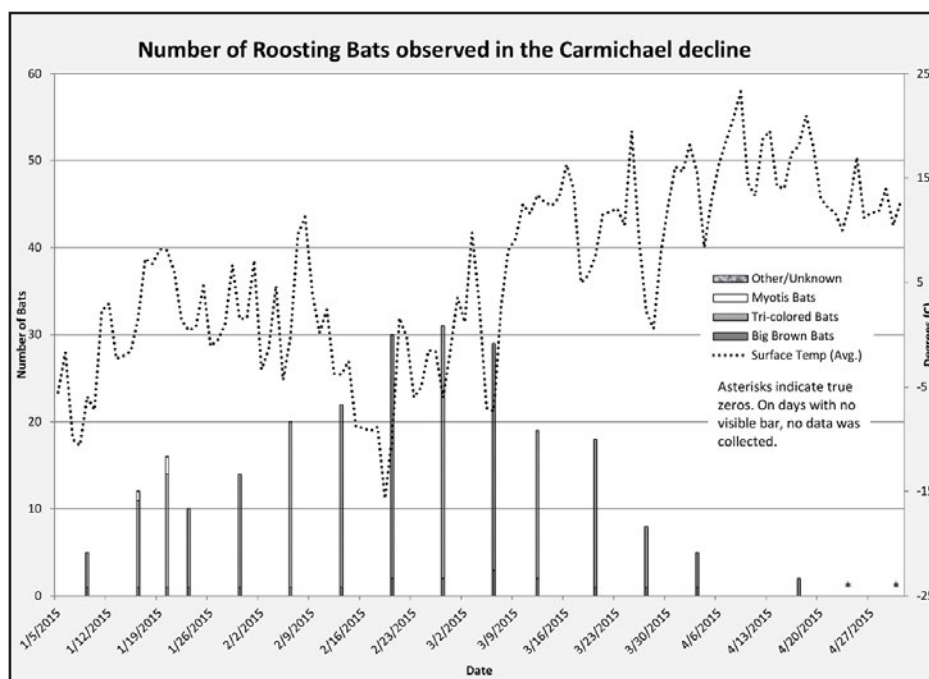


Figure 3: This graph depicts the number of bats presumed alive that were observed along the Carmichael Entrance Decline transect in 2015 split by species according to the date. The average surface temperature is also plotted as an indicator of climactic conditions.

winter within the cave that can be attributed to WNS when you combine the flying bats from the regular transect route with the flying bat data collected by the Division of Interpretation (Figure 4).

Interestingly, while the number of roosting bats along the Domes and Dripstones route was only ~3% of the number of bats observed roosting in the Historic Section, ~31% of the reported flying bats came from this route. It also had more bat-human contacts than the Historic Section. Out of the eleven contacts that occurred in winter 2014-15, seven were along the Domes and Dripstones route while three were in the Historic Section. The remaining contact occurred on the surface along Big Hollow Trail.

This leads to an interesting question – why? Could it be due to the Domes and Dripstones route being on the warm end of the tri-color bat's ideal hibernation temperature range? Further research could look into this discrepancy and explore this interesting aspect of WNS bat behavior at Mammoth Cave National Park.

The last component of our data collection is the testing results of the collected dead bats for both rabies and White Nose Syndrome. Out of the 75 dead bats collected throughout the winter and submitted for testing, none tested positive for rabies. The results are not yet complete for the WNS assessment, but it appears likely that they will all tests positive.

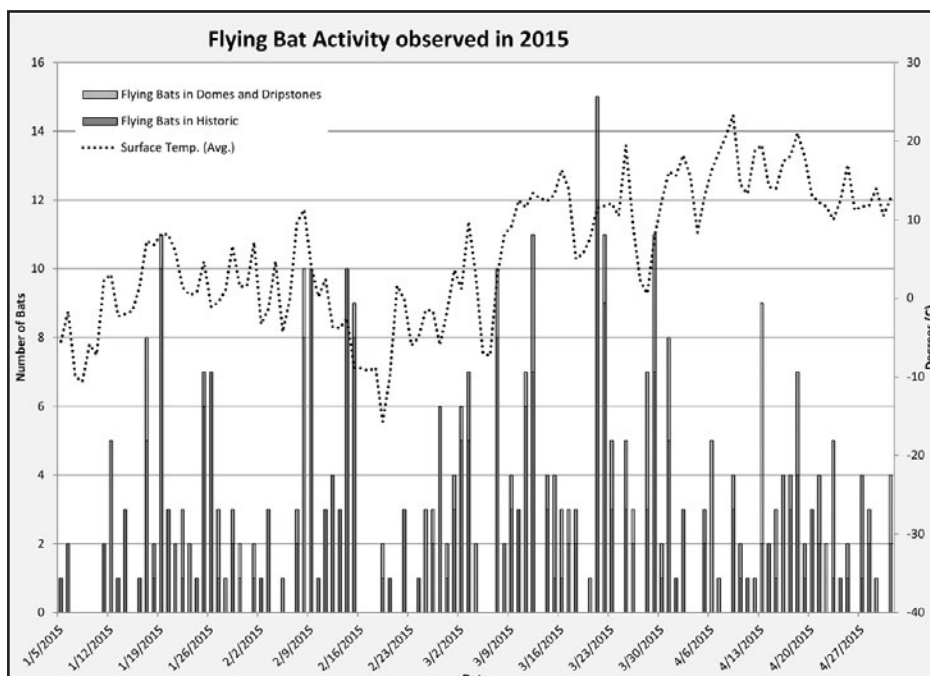


Figure 4: This graph depicts the number of bats observed flying throughout the Historic Section of Mammoth Cave and along the Domes and Dripstones route collected by both the observers completing the transects and Interpreters as they conducted cave tours with the public. The average surface temperature is also plotted as an indicator of climactic conditions.

Conclusion

This monitoring effort was unique and rewarding. It is one of the most comprehensive looks at WNS afflicted bat behavior, and the only data available on bat behavior for a National Park show-cave and how WNS may affect the National Park Service mission. The bats at Mammoth Cave are altering their behavior. We are seeing flying bats throughout the day in-cave, and an interesting trend in the bat populations as WNS influences their roosting choices.

As the only National Park Service site to contend with this disease and manage a year-round show cave operation, there are many lessons to be learned here. As WNS progresses at Mammoth Cave National Park will we continue to see the behaviors and trends observed in our first year of data? Why do the bats in different cave sections exhibit varied activity levels? How can we continue to monitor and preserve the changing bat populations on park without impacting the public's ability to enjoy their public lands?

References

- Carson, Vickie, 2013. White Nose Syndrome confirmed in Park Bats. National Park Service. <<http://www.nps.gov/macal/learn/news/nr-wnsinparkbats.htm>> Accessed on: February 2016.
- Coleman, Jeremy, et al., 2011. White Nose Syndrome National Plan. US Interagency working group. <<https://www.whitenosesyndrome.org/book/export/html/57>>. Accessed on: March 2016.
- Toomey, Rick and Steve Thomas, 2011. White Nose Syndrome Response Plan. Mammoth Cave National Park. <http://www.nps.gov/macal/upload/Mammoth_Cave_NP_WNS_Response_Plan_FINAL.pdf> Accessed on: January 2016.
- Wong, David and Cara Cherry, 2015. White-nose syndrome in bats and risk for bat human contact. NPS Office of Public Health. 8 pp.

Evaluating the Energetic Value of Lepidoptera Using Bomb Calorimetry

Shelby A. Fulton¹, Luke E. Dodd¹, and Lynne K. Rieske²

¹ Department of Biological Sciences, Eastern Kentucky University

² Department of Entomology, University of Kentucky

Abstract

Lepidopterans are a core resource for many of North America's insectivorous bats. These predators consume Lepidoptera of varying sizes, and some bat species remove the wings of lepidopteran prey prior to consumption. Selection of larger prey and subsequent wing removal may allow bats to optimize the energetic value afforded by lepidopteran prey. To explore the relationships between caloric yield, body size, and wing presence, laboratory-reared *Trichoplusia ni* moths were grouped into large and small size classes. Wings were removed from half of the moths in each size class. Bomb calorimetry was used to determine the gross heat (cal/g) of moths in each treatment. To account for potential differences in energetic value among species, specimens of *Malacosoma americanum*, *Halysidota tessellaris*, and *Iridopsis sp.* moths were also combusted. Larvae of *M. americanum* were field-collected in April 2012 and reared in the laboratory. Adult *H. tessellaris* and *Iridopsis sp.* moths were wild-caught using an illuminated substrate at Mammoth Cave National Park in June - July 2015. No differences were detected for size class or wing condition of *T. ni* ($P \geq 0.05$). Additionally, no differences were detected in the caloric yields of the various lepidopteran species, except between *Ma. americanum* and *Iridopsis sp.* ($P = 0.03$). These results suggest that lepidopteran prey of various species and sizes may be of similar prey quality, and that the removal of wings by bats may be unrelated to caloric yield. Even so, we believe the lack of differences detected in this study indicate that our approach was likely too coarse of a method to capture subtle energetic differences among lepidopteran prey. Future studies including additional insect orders will clarify the potential limitations of conducting prey quality studies by bomb calorimetry.

Introduction

Lepidoptera are a core resource for many of North America's insectivorous bats, and have been detected in the diets of all Kentucky bat species tested (Lacki et al. 2007). The gleaner species *Myotis septentrionalis* and *Corynorhinus rafinesquii* are lepidopteran specialists, with this prey taxon representing nearly 50% of the diet of *M. septentrionalis* (Dodd et al. 2012) and more than 80% of the diet of *C. rafinesquii* (Lacki and Dodd 2011). Lepidoptera are also common in the diets of more generalist predators, including *M. lucifugus*, *M.*

sodalis, and *Perimyotis subflavus*. Although *M. lucifugus* and *M. sodalis* may consume diverse diets, these species often rely on lepidopteran prey (Brack and LaVal 1985, Whitaker 2004, Feldhamer et al. 2009, Clare et al. 2014). The generalist predator *P. subflavus* opportunistically consumes soft-bodied arthropods, including lepidopterans (Whitaker 2004, Lacki et al. 2007, Dodd et al. 2014).

The ubiquity of Lepidoptera as a prey resource for insectivorous bats is thought to be a consequence of high digestive efficiency. The carbohydrate chitin, which

forms arthropods' hard exoskeletons, is difficult for most mammals to digest (Strobel et al. 2013). However, some bat species have the ability to optimize digestion of arthropod prey due to specialized gastrointestinal microflora (Strobel et al. 2013, Whitaker et al. 2004). These bats, including *M. septentrionalis*, *M. lucifugus*, *M. sodalis*, and *P. subflavus*, host chitinase-producing bacteria in the digestive tract (Whitaker et al. 2004). The enzyme chitinase promotes the breakdown of chitin, but does not allow it to be completely digested. As a result, insects with high chitin levels have low digestive efficiency (Barclay et al. 1991).

Some bats (e.g., *Corynorhinus* species) reject lepidopteran body parts such as the legs and wings (Lacki and Dodd 2011). This behavior may be a result of low palatability, but is thought to be due to low digestibility of these chitin-rich structures (Barclay et al. 1991). Smaller moths have lower digestive efficiency, likely due to the increased difficulty of removing indigestible or unpalatable structures from small prey (Barclay et al. 1991). Although larger moths are more digestible, it is not yet clear whether selection of larger moths affords a caloric benefit.

The relationships between caloric yield, body size, and wing presence are poorly understood. Thus, our objectives were: (1) explore the relationships between caloric yield, body size, and wing presence by determining the mean gross heat (cal/g) generated across large, small, winged, and wingless representatives of a model lepidopteran species (*Trichoplusia ni*), (2) investigate potential differences in energetic value among species by using bomb calorimetry to combust *Malacosoma americanum*, *Halysidota tessellaris*, and *Iridopsis* sp. moths, and (3) evaluate the overall viability of bomb calorimetry as a

method of conducting prey quality studies.

Methods

Malacosoma americanum tents and larvae were field-collected in April 2012 at Mammoth Cave National Park (N 37° 11.83', W 86°04.50'). Tents (n = 1-3) were placed in plastic housing (32 cm × 26 cm × 9 cm) lined with paper towels to absorb moisture and provide substrate. The developing insects were supplied ad libitum with fresh, field-collected *Prunus* sp. foliage. Throughout the three-week rearing process, some tents were disposed of to maintain hygienic conditions. Pupae were subsequently removed from plastic housing and placed individually in plastic diet cups (30 ml) until emergence. Adult moths were flash-frozen within 24 hr of emergence; adult moths (in diet cups) were submerged in liquid nitrogen for 5-10 seconds, and immediately stored in a -80°C freezer.

Larvae of *T. ni* were reared communally from 25 eggs on 110 g of a pinto bean-based diet in a 240 ml Styrofoam cup kept at ambient conditions (Evenden and Haynes 2001). Other details of the rearing methods are described by Shorey and Hale (1965). Pupae were separated, sexed, placed individually in diet cups (30 ml), and flash-frozen in liquid nitrogen within 24 hr of adult emergence. Specimens were then stored in a -20°C freezer. Adult *T. ni* were divided into large and small size classes (individual masses of 118 ± 0.80 and 87 ± 0.69 mg, respectively), and wings were removed from half of the moths in each size class.

Wild-caught moths were collected from June - July 2015 at the Mammoth Cave International Center for Science and Learning (N 37° 12.44', W 86° 7.93'). A cotton sheet was hung vertically and stretched taut at ground level; the sheet was

illuminated between approximately 2000 and 2300 hours with a 10 w black light and electrical harness (Universal Light Trap, Bioquip Products, Rancho Dominguez, CA, USA) (Figure 1). Lepidoptera attracted to the sheet were collected in plastic diet cups and immediately placed on ice. Specimens were temporarily stored at -18°C and transferred to -80°C within 7 d. Although numerous taxa were collected, *H. tessellaris* and *Iridopsis sp.* were selected for combustion due to their ready abundance and conspicuous appearance (Covell 2005).

To prepare for combustion, all frozen Lepidoptera were transferred to open, heat-resistant vials and dried in a 55°C oven for approximately 24 hr. Specimens were consolidated by treatment (Table 1) and ground with a mortar and pestle for 30-60 seconds until a coarse powder was attained. A Parr 1281 Oxygen Bomb Calorimeter (Parr Instrument Company, Moline, IL, USA) was calibrated daily using a 1.0 g benzoic acid



Figure 1: Cotton sheet deployed at Mammoth Cave National Park to sample Lepidoptera, illuminated by 10 w black lights with electrical harnesses.

Table 1: Summary of *Trichoplusia ni*, *Malacosoma americanum*, *Halysidota tessellaris*, and *Iridopsis sp.* treatments. The treatment marked with an asterisk was not included in the initial comparison of small vs. large-bodied and winged vs. wingless *T. ni*, but was included in the comparison of species. N = number of samples combusted per treatment.

Species	Size Class	Wings	Sample Weight (mg)	N
<i>T. ni</i>	Large	Yes	250	6
<i>T. ni</i>	Large	No	250	6
<i>T. ni</i>	Small	Yes	250	6
<i>T. ni</i>	Small	No	250	6
<i>T. ni</i> *	-	Yes	250	2
<i>Ma. americanum</i>	-	Yes	200-250	5
<i>Ma. americanum</i>	-	Yes	400-450	5
<i>Ma. americanum</i>	-	Yes	600-650	5
<i>Ma. americanum</i>	-	Yes	800-850	3
<i>H. tessellaris</i>	-	Yes	250	7
<i>Iridopsis sp.</i>	-	Yes	250	4

pellet (Parr Instrument Company, Moline, IL, USA). To determine whether sample weight affects gross heat generated by bomb calorimetry, we combusted *Ma. americanum* samples weighing 200-250 mg, 400-450 mg, 600-650 mg, and 800-850 mg. Following this assessment of methods, a standard sample weight of 250 mg was used for *T. ni*, *H. tessellaris*, and *Iridopsis sp.* treatments. The number of bomb calorimetry samples combusted was dependent upon the volume of processed lepidopteran material available for each treatment. All treatments were combusted according to instructions provided by the bomb calorimeter manufacturer.

We determined the mean gross heat \pm SE (cal/g) generated by the combustion of each treatment. A one-way analysis of variance (ANOVA) was used to test for differences between *Ma. americanum* sample weight

classes, and a 2×2 ANOVA was used to test for differences between *T. ni* treatments. To test for potential differences in energetic value among species, Wilcoxon Rank-Sum tests were used to make pairwise comparisons (using 250 mg samples).

Results

Malacosoma americanum was found to have a significantly greater caloric yield than *Iridopsis sp.* ($W_{5,4} = 19$, $P = 0.03$), although no additional differences were detected between pairwise comparisons across species (Figure 2). No differences were detected between any *Ma. americanum* weight classes ($F_{3,14} = 1.6$, $P > 0.05$) (Figure 3) or *T. ni* treatments ($F_{3,23} = 0.86$, $P > 0.05$) (Figure 4).

Discussion

The lack of differences detected between *Ma. americanum* weight classes suggests the gross heat generated by combustion is likely not affected by sample weight. These data indicate that any sample weight (adhering to manufacturer's specifications for safe calorimeter usage) could be combusted effectively. Based on these findings, we recommend that future studies reduce sample weights to conserve raw material and maximize the number of combustion reactions possible.

We found no differences in energetic value between any *T. ni* treatment, suggesting that the removal of lepidopteran wings by bats may be unrelated to caloric yield. These results support the commonly accepted hypothesis that bats reject lepidopteran wings due to indigestibility (Barclay et al. 1991, Lacki and Dodd 2011). The lack of any significant differences between large and small *T. ni* indicates that caloric yield is independent of body size. However, *Ma. americanum* appears

to have a significantly greater caloric yield than *Iridopsis sp.*, likely due to the larger body size of *Ma. americanum*. This explanation is supported by previously published literature regarding the energy density of fish; Glover et al. (2010) found

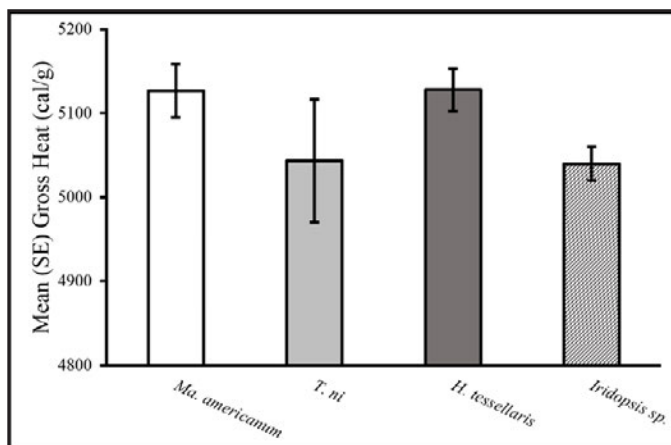


Figure 2: Mean gross heat \pm SE (cal/g) generated by combustion of coarsely ground samples of *Malacosoma americanum*, *Trichoplusia ni*, *Halysidota tessellaris*, and *Iridopsis sp.* using bomb calorimetry. We combusted five samples of *Ma. americanum*, twenty-six of *T. ni*, seven of *H. tessellaris*, and four of *Iridopsis sp.*

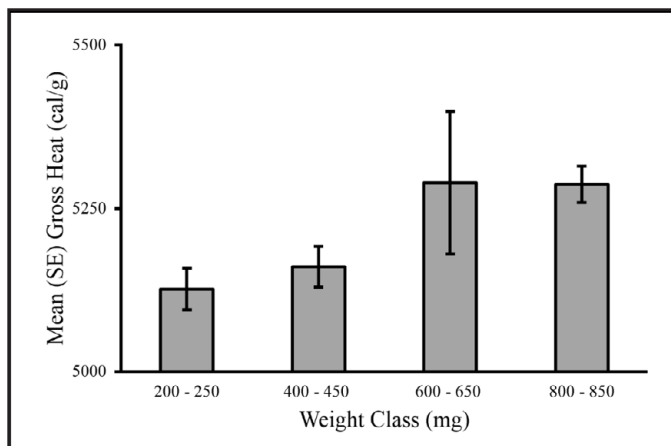


Figure 3: Mean gross heat \pm SE (cal/g) generated by combustion of coarsely ground *Malacosoma americanum* samples using bomb calorimetry. Five samples weighing 200-250 mg, 400-450 mg, and 600-650 mg, and three samples weighing 800-850 mg were combusted.

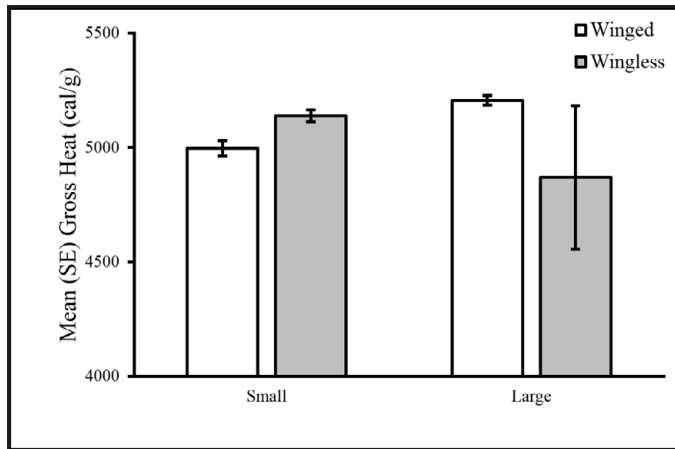


Figure 4: Mean gross heat \pm SE (cal/g) generated by combustion of coarsely ground *Trichoplusia ni* samples using bomb calorimetry. Six samples were combusted per treatment (small with wings present, small with wings removed, large with wings present, large with wings removed).

that the caloric yield of largemouth bass is directly related to body mass, with larger bass generally possessing greater energetic density.

Given that Lepidoptera are relatively soft-bodied (Freeman 1981), we suspect these prey may have comparatively less chitin than many insect orders, thus allowing predators to maximize digestive efficiency. Although it is likely that consuming Lepidoptera affords a digestive advantage, the similarity in energetic value among study species may suggest that lepidopteran prey of various species and sizes is of similar prey quality. However, based on the inconsistency of our results regarding caloric yield and body size, we believe the lack of differences detected in this study indicates our technique is likely too coarse of a method to capture subtle energetic differences among Lepidoptera. Future studies including additional insect orders will clarify the potential limitations of conducting prey quality studies by bomb calorimetry.

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Literature Cited

- Barclay, R.M.R., M.A. Dolan, and A. Dyck. 1991. The digestive efficiency of insectivorous bats. *Canadian Journal of Zoology* 69:1853-1856.
- Brack, V., and R.K. Laval. 1985. Food habits of the Indiana Bat in Missouri. *Journal of Mammalogy* 66:308-315.
- Clare, E.L., W.O.C. Symondson, H. Broders, F. Fabianek, E.E. Fraser, A. Mackenzie, A. Boughen, R. Hamilton, C.K.R. Willis, F. Martinez-Nuñez, A.K. Menzies, K.J.O. Norquay, M. Brigham, J. Poissant, J. Rintoul, R.M.R. Barclay, and J.P. Reimer. 2014. The diet of *Myotis lucifugus* across Canada: assessing foraging quality and diet variability. *Molecular Ecology* 23:3618-3632.
- Covell, C.V. 2005. A field guide to moths of eastern North America: special publication number 12. Virginia Museum of Natural History, Martinsville, Virginia. p. 496.

- Dodd, L.E., E.G. Chapman, J.D. Harwood, M.J. Lacki, and L.K. Rieske. 2012. Identification of prey of *Myotis septentrionalis* using DNA-based techniques. *Journal of Mammalogy* 93:1119–1128.
- Dodd, L.E., M.J. Lacki, D.C. Cox, and L.K. Rieske. 2014. Prey consumed by bats across central Appalachia prior to the detection of White-nose Syndrome. *Journal of the Kentucky Academy of Science* 75:85-93.
- Evenden, M.L., and K.F. Haynes. 2001. Potential for the evolution of resistance to pheromone-based mating disruption tested using two pheromone strains of the cabbage looper, *Trichoplusia ni*. *Entomologia Experimentalis et Applicata* 100:131-134.
- Feldhamer, G.A., T.C. Carter, and J.O. Whitaker. 2009. Prey consumed by eight species of insectivorous bats from southern Illinois. *American Midland Naturalist* 162:43-51.
- Freeman, P. W. 1981. Correspondence of food habits and morphology in insectivorous bats. *Journal of Mammalogy* 62:154-159.
- Glover, D.C., D.R. DeVries, R.A. Wright, and D.A. Davis. 2010. Sample preparation techniques for determination of fish energy density via bomb calorimetry: an evaluation using Largemouth Bass. *Transactions of the American Fisheries Society* 139:671-675.
- Lacki, M.J., S.K. Amelon, and M.D. Baker. 2007. Foraging ecology of forest bats. Pp. 83–128, In M.J. Lacki, J. P. Hayes, and A. Kurta (Eds.). *Bats in forests: conservation and management*. Johns Hopkins University Press, Baltimore, Maryland.
- Lacki, M.J., and L.E. Dodd. 2011. Diet and foraging behavior of *Corynorhinus* in eastern North America. Pp. 39–52, In S.C. Loeb, M.J. Lacki, and D.A. Miller (Eds.). *Conservation and management of big-eared bats: a symposium*. US Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina.
- Shorey, H.H., and R.L. Hale. 1965. Mass-rearing of the larvae of nine noctuid species on a simple artificial medium. *Journal of Economic Entomology* 58:522-524.
- Strobel, S., A. Roswag, N.I. Becker, T.E. Trenczek, and J.A. Encarnação. 2013. Insectivorous bats digest chitin in the stomach using acidic mammalian chitinase. *PloS ONE* 8:e72770.
- Whitaker, J.O. 2004. Prey selection in a temperate zone insectivorous bat community. *Journal of Mammalogy* 85:460–469.
- Whitaker, J.O., H.K. Dannelly, and D.A. Prentice. 2004. Chitinase in insectivorous bats. *Journal of Mammalogy* 85:15-18.

Organization and Development of the Eyes of *Ptomaphagus hirtus*, the Trogllobiotic Small Carrion Beetle of Mammoth Cave

Markus Friedrich¹, Jasmina Kulacic¹, and Elke Buschbeck²

¹ Wayne State University

² University of Cincinnati

Abstract

Obligatory cave species (troglobionts) exhibit a consistent suite of dramatic regressive traits such as the strong or complete reduction of the eyes. We have begun to study *Ptomaphagus hirtus*, the highly cave adapted small carrion beetle, which is a signature inhabitant of Mammoth Cave. Earlier work concluded that *P. hirtus* is functionally blind, but equipped with degenerate eye structures. Following up on molecular evidence that *P. hirtus* possesses a functional visual system, we explored the organization and development of its presumably functional but highly reduced lateral eyes. Using electron microscopy and immunohistochemical approaches we found that a single *P. hirtus* eye contains approximately 130 photoreceptor cells and 70 additional cells of yet unknown fate and function. In mature adult animals, this cell population populates a cuticle chamber that is covered by a single lens. Our developmental studies reveal that this lens is formed unexpectedly late in the life of *P. hirtus*. While the lenses of the compound eyes of surface-living insects are fully formed during pupation, in *P. hirtus* lens formation initiates in the young adult animal and takes about 12 weeks to completion. To the best of our knowledge, *P. hirtus* represents the first insect - if not animal - example in which the lens is added to the eye during adulthood.

Strip Adaptive Cluster Sampling with Application to Cave Crickets

Kurt Lewis Helf¹, Tom Philippi¹, Bill Moore¹, and Lillian Scoggins¹

¹ I&M Division/NPS

Introduction

Most cave ecosystems depend on the transport of organic matter from the surface by both passive (e.g., water) and active (e.g., cave crickets) agents (Culver and Pipan 2009, Schneider 2009). Subsidized ecosystems are vulnerable to perturbations that affect the production, transfer, and use of those subsidies (Riley and Jefferies 2004). Perturbations on a regional and local scale can affect productivity on the surface and the ability of surface-feeding cave organisms to access it and thus alter the amount of the subsidy being transferred to the subsurface. Important insights into the individual and collective effects of local changes on actively subsidized cave terrestrial ecosystems in the southeast can be gained through assessing the modulation of cave cricket entrance populations.

Cave crickets (*Euhadenoecus* and *Hadenoecus* sp.) are commonly found roosting in high densities just inside cave entrances throughout the southeastern United States. They are omnivores that feed on the surface and transfer nutrients-in the form of guano, eggs, and bodies-into the subsurface habitat.

In the Mammoth Cave region, cave crickets (*Hadenoecus subterraneus*) are a keystone species in that their entrance populations subsidize up to three separate cave invertebrate communities through the active, regular transfer of organic matter from the surface to the subsurface (Poulson and Lavoie 2000, Lavoie et al. 2007). The communities they subsidize can include rare, sometimes endemic, obligate cave-dwelling invertebrates (Culver et al. 2000).

Perturbations affecting the availability of surface resources to cave crickets, such as contingent climatic conditions, can alter the amount of nutrient subsidies they transfer to their dependent subsurface communities. Poulson et al. (1995) showed conditions favorable to cave crickets foraging on the

surface (i.e., warm winters, cool summers, and above average precipitation) were correlated with the highest abundance and diversity of the cave invertebrate community dependent on cave cricket guano and declined in years with cold winters, hot summers, and below average precipitation.

Helf's (2003) study provided rigorous support for Poulson et al.'s (1995) data in that it showed a significant inverse relationship between cave crickets' use of artificial bait patches and precipitation among growing seasons, strongly suggesting cave crickets fed more on artificial bait patches due to decreased primary productivity on the surface.

Extremes in maximum temperature and precipitation events across the Southeast, predicted by mid-century (Fisichelli 2013, Kunkel et al. 2013), could lead to reduced primary productivity on the surface. While precipitation and primary productivity are often positively correlated the predicted concomitant temperature increases may increase evaporation and so lead to a net loss in moisture available to surface communities

(Young et al. 2011). Drier surface conditions may directly reduce the amount of organic material available to cave crickets or indirectly reduce its availability by creating suboptimal foraging conditions that preclude cave cricket foraging bouts (Studier et al. 1987, Poulson et al. 1995, Helf 2003, Lavoie et al. 2007).

On the other hand, minimum temperatures below freezing are also predicted to decrease by 20-25 days/year (Fisichelli 2013) which suggests increased foraging opportunities for cave crickets during winter months. Increases in winter foraging opportunities may compensate for decreased foraging opportunities in summer.

Management actions, such as altered cave entrance configuration, can also affect the flow of allochthonous organic matter into caves due to their effects on cave cricket foraging behavior and population structure (Fry 1996, Poulson et al. 2000, Helf 2003). Indeed, from 1993-1996, Mammoth Cave National Park (MACA) facilities and resources management personnel retrofitted cave entrance doors with airlocks to mitigate the negative effects of cold, dry winter air on the growth and formation of speleothems and biological communities (Fry 1996).

To assess the potential effects of this program MACA funded visual censuses of cave cricket populations at nine cave entrances, six with varying degrees of anthropogenic modification and three without, from 1994-1998. Among all cave entrances overall cave cricket abundance declined significantly from 1994-1997 (Poulson et al. 2000).

Monitoring Objectives

The Cumberland Piedmont Network's primary monitoring goal is to assess status and trends of MACA's cave cricket entrance

populations and their habitat use; we have three monitoring objectives:

- **Monitoring Objective 1:** To determine the status and trend of cave cricket entrance population size, life stage, and sex ratio among 15 developed and undeveloped cave entrances at Mammoth Cave National Park during biannual visits.
- **Monitoring Objective 2:** To determine effects of management decisions (e.g., alteration of cave entrances) at Mammoth Cave National Park on cave cricket populations within selected developed caves. Specific monitoring foci will include assessment of the impact of cave-entrance modification on cave cricket population size and structure and localized impacts of infrastructure installation/improvement on cave cricket habitat use.
- **Monitoring Objective 3:** To determine if a correlation exists between cave temperature, relative humidity and air flow trends, surface temperature, relative humidity and precipitation trends and: 1) trends in cave cricket entrance population size, life stage, and sex ratio, and 2) trends in spatial distribution within 15 developed and undeveloped cave entrances in Mammoth Cave National Park using biannual and continuous automated sampling.

Field Methods

For this protocol the overall statistical population of interest is the set of cave crickets using a set of cave entrances in MACA. Inferences will be made comparing cave cricket entrance populations between developed (i.e., entrances with bat gate

or door(s), significant modification to its entrance/passage or significant infrastructure, such as a lighting system, or regular tours) and undeveloped entrances (i.e., entrance with or without bat gate, light or no modification to its entrance/passage or no infrastructure or no tours).

Because neither a complete census of cave entrances nor a complete census of cave cricket entrance populations is possible, this monitoring protocol requires two separate sampling frames: the selection of which cave entrances to monitor and defining how to sample within cave entrances. Such multi-stage sampling designs (Thompson 2002) are common for large-scale environmental surveys. At the broad level of cave entrances our sample frame consists of 15 cave entrances within MACA's boundary stratified by whether they are developed or undeveloped.

Because neither a complete census of cave entrances nor a complete census of cave cricket entrance populations is possible, our target population requires a multistage, adaptive sampling design (Thompson 2002, Salehi and Seber 2013) for defining how to sample within cave entrances. The within-entrance component of cave cricket sampling is designed to provide estimates of the total number of crickets in that entrance, separate estimates of numbers of individuals by life stage and sex, and estimates of counts as a function of distance from the opening to the surface.

For sampling rare, clumped distributions adaptive cluster sampling and related methods have the potential to be much more efficient than simple random sampling in that their variance declines with sample size relative to simple random sampling (Thompson 2002). In addition to the estimates of total population size, adaptive

cluster sampling automatically partitions the population size into components of cluster size and numbers of clusters, which can be informative for interpreting temporal changes in population size within each entrance.

Thus, this protocol uses a combination of a linear transect, (i.e., baseline) running down the length of the passageway from the entrance toward the depth of the cave, and strip adaptive cluster sampling (Thompson 2002) with strip locations defined by positions along that baseline. Generalized Random Tessellation Stratified (GRTS) sampling is used to select strip locations along the baseline to provide spatial balance to the survey.

During a sampling event one crew, comprised of two individuals, surveys a randomized selection of two cave entrances per day. A fiberglass measuring tape, placed in the same location each sampling event, serves as the baseline on which the randomized strips are positioned. The strips are defined by two red laser lines separated by 10cm, perpendicular to the baseline, and projected on the walls and ceiling of the passageway (Figure 1).

When a cricket is detected within a strip we use a plotless adaptive cluster sampling design (Mosquin and Thompson 1998). That is, for each cricket in a strip, any other crickets within 10cm are added to that cluster, and any crickets within 10cm of those crickets, recursively, until no additional crickets are within 10cm of any cricket in the cluster (Figure 2).

Digital images of each cave cricket clusters are captured. From these images counts of cave crickets, both inside and outside the strip, are obtained during subsequent image analysis. Data on cave cricket entrance populations are derived from a careful

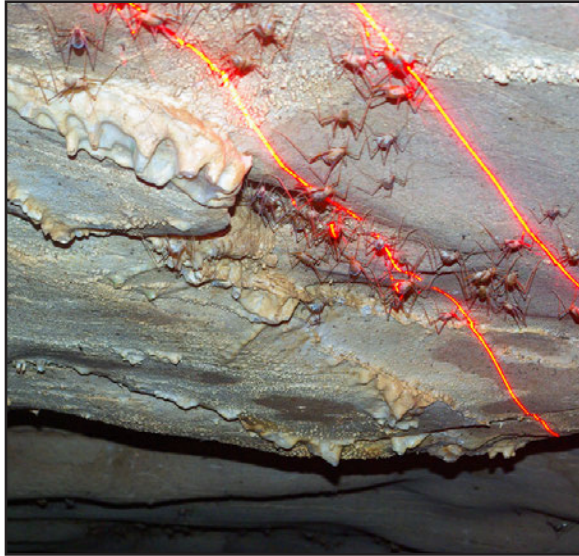


Figure 1: Cluster of cave crickets captured by 10cm wide laser strip projected on the ceiling at Frozen Niagara entrance.

analysis of the digital images as shapefiles in ArcMap. Ancillary data on clusters include mapping the location of each sampled roosting cluster, the width (i.e., extent) of sampled roosting clusters, and roost site descriptive characteristics (e.g., located on wall or ceiling).

Sampling events for cave cricket monitoring are conducted biannually. In a sampling year two sets of sampling events are conducted at all 15 sampling sites. Sampling events occur within a two-week period each “shoulder season” (i.e., May-June and October-November), at each of the 15 selected cave entrances at MACA.

Previous monitoring efforts show these months are the best times of year to maximize sample size and reduce day to day variability among entrance populations because equable weather creates optimal foraging conditions on the surface and similar proportions of cave cricket entrance populations forage on any given evening

(Helf 2003, Lavoie et al. 2007). Due to drought conditions during the mid-summer through late fall months cave cricket abundance on any given day is highly variable and so the potential for substantial sampling noise is greatly increased.

Prior to each sample event or group of sampling events (a grouping of cave entrances to be visited during a sampling session), the project leader conducts a GRTS draw to randomize the order in which caves are visited and the order in which locations on the baseline are surveyed during in-cave sampling.

The R code which generates these draws harvests a list of entrances to be visited, within-cave sample sizes, and the sequential order of caves visited from the previous sampling event. This code then formats and populates field data sheets in Microsoft Word™.

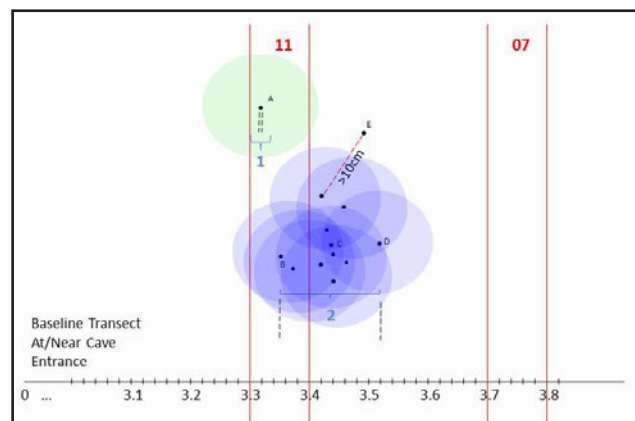


Figure 2: Schematic diagram of the plotless strip adaptive cluster sampling method used to monitor cave cricket entrance populations at Mammoth Cave National Park. Note that because the probability a cluster of crickets will be detected is dependent only on the extent of that cluster along the baseline, the grid and virtual quadrats need not exist. Any cricket intersected by a strip triggers a cluster; any crickets within 10cm radius of a cricket in a cluster are added to that cluster, and in turn have their 10cm radii searched.

In addition to generating the primary field data sheets, R code is also be used to create temporary tables in the protocol database. The values in these tables can then be utilized during the data entry process reducing manual data entry. R code is also used to pull and summarize the counts from the various shapefiles generated and append values in the temp_* tables in Access.

Data Management and Analysis

In short, the majority of data entry is not accomplished via the traditional method whereby an individual sits down at their computer with a completed field data sheet and enters each value into a similarly designed form on the computer. Instead much of the data are populated into temporary tables in the database via R code.

Thus the data entry process includes: ensuring data are accurately parsed to the correct location/event combinations in the 'permanent' tables in the database; data records are complete; and finally, entry of remaining data elements from the field data sheets (e.g., notes fields, cricket cluster locational information) is completed. A series of Quality Assurance/Quality Control checks are in place to assist in this process.

Data from the MACA cave cricket monitoring project are analyzed/summarized in multiple ways:

- Annual status summary of cave cricket monitoring highlights,
- Analysis of trends in key measures over time; typically summarized every five years,
- Evaluations of relationships between key ecosystem drivers/attributes/stressors and key measures including cave and surface meteorology and infrastructure installation/maintenance.

Data from the MACA cave cricket monitoring protocol support both non-adaptive estimates based on the counts inside strips and strip adaptive cluster sampling (SACS) estimates based on the counts by clusters. SACS should be substantially more efficient (i.e., lower uncertainty about estimates for a given sampling effort) than non-adaptive estimates based on just the crickets inside strips (Thompson 2002).

However, because the rules for adaptively sampling clusters are based on all crickets, strip adaptive cluster estimates of the total counts for some sub populations (e.g., juveniles) might be less efficient than non-adaptive estimates. Therefore, as is common practice in these applications, we will compute both non-adaptive estimates based on strips and SACS estimates based on clusters, for the total population of crickets, and for the subpopulations based on sex and life stage (Ver Hoef and Boveng 2007).

Given these estimates of the total numbers of crickets at each cave entrance and sampling event, temporal trends will be tested as both generalized linear mixed models (GLMM using function `glmer` in the `lme4` R package) and generalized estimating equations (GEE using function `geeglm` in the `geepack` R package). Both of these approaches are appropriate for count data that are likely to be overdispersed relative to the Poisson error distribution expected for counts of independently occurring events. For technical reasons, the `glmer` approach fits overdispersed Poisson as a two-parameter negative binomial distribution. The `geeglm` approach adds an overdispersion parameter and treats the error distribution as `quasipoisson`.

These models also support tests for differences in trend among cave entrances

or among groups of cave entrances (e.g., between developed and undeveloped entrances). However, because the monitored entrances are not a probability sample of any defined population of entrances, the tests support inferences about only these particular entrances, and not to unsampled developed or undeveloped entrances.

The status of cave cricket entrance populations over time is one of the objectives of this monitoring protocol and is effectively presented by a form of control chart. The estimated population size for the most recent sampling event at each entrance is plotted over a boxplot of the estimates from previous sampling events (Figure 3).

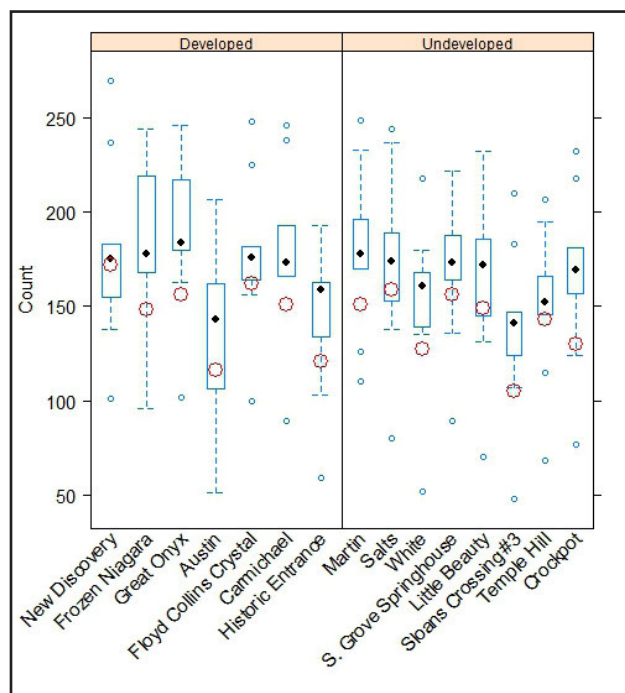


Figure 3: Mockup of control chart depicting ten years of estimates of monitored cave cricket entrance populations. The most recent sampling event (large, open circles) are plotted over a boxplot of estimates from previous sampling events. Note: dots indicate the median of the data and small, open circles are outliers.

This produces a visual representation of which, if any, of the monitored cave entrances have recent population estimates high or low relative to that cave entrance's historic range of variability. If some current values are high and some are low, there is cave entrance-specific fluctuation. If most cave entrances deviate in the same direction that suggests a region-wide driver such as surface weather or food sources.

Estimates of total cave cricket entrance populations, sex, and life stage, are only one aspect of cave cricket status in these entrances. Other aspects may also be informative of impacts of cave entrance management, climate, or other stressors. For instance, the distribution of roosting crickets as functions of distances from the cave entrance to aboveground might shift due to changes in air circulation or meteorological conditions in the first few tens of meters of the passageway.

This sampling and data collection scheme supports estimates of several such secondary aspects. Temporal changes in total cave cricket entrance population will be estimated and also partitioned into several components of numbers of clusters and the distribution of the numbers of crickets per cluster (Figure 4). The distribution of crickets as a function of distance from the surface can be characterized as cumulative distribution functions estimated for individual cave entrances and each cave entrance can support tests for shifts in those distributions over time.

To reduce the time and effort normally required to write annual status and trend analysis reports R code, used to access standard databases to produce informative tables and figures, will be added during initial report writing in MS Word™. Thus, when new data are entered into the database

the R code run on those data will produce new report components.

For consistency between/among report intervals all of the formatting, boilerplate background text, and forms of tables and figures will remain the same year after year. This scripting of the workflow provides both documentation and automation, and makes the work reproducible from one year to the next.

Reports generated by this monitoring project will consist of three major types. Trip Reports will be written to briefly summarize sampling trips for park staff. Brief follow-up trip reports will be completed within two weeks after each sampling trip. Annual Status Reports and Trend Analysis Reports will provide park management and other interested parties technical and interpretive information about the status and trends being detected in the monitored resource.

The annual status report may include descriptive statistics, graphic analysis, and correlative statistics on cave cricket entrance populations and will be produced in late winter after the preceding year's monitoring events and subsequent data analyses are completed. This type of report will target MACA's superintendent and resource managers and will provide them with a view of the current status and short-term shifts in any parameter(s) of the resource. Annual status reports will be submitted to the Natural Resources Data Series for publication.

The trend analysis report will typically be generated every fifth year, beginning five years after the formal implementation of the monitoring protocol. The trend analysis report will also address patterns in cave cricket population structure and dynamics among developed and undeveloped caves, using similar components as the annual

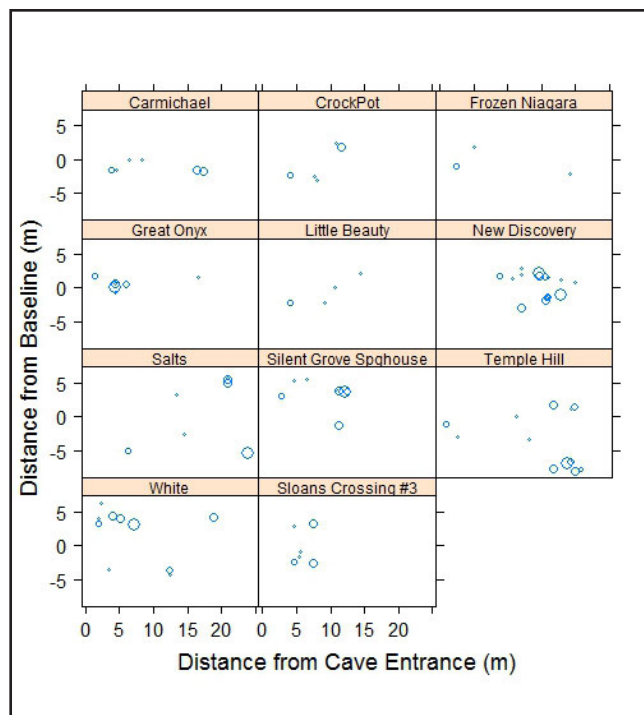


Figure 4: Proportionally sized bubble plot of cave cricket clusters from pilot data. The y-axis is the cluster's distance from the baseline and side of the passage on which they were located (positive = left and negative = right). The x-axis is the cluster's distance from the cave entrance. Proportional bubble plots are an informative way to display data on the location, number and size of cave cricket clusters.

status report, but will do so with cumulative data on a scale spanning multiple years.

Literature Cited

- Culver, D. C., L. L. Master, M. C. Christman, and H. H. Hobbs. 2000. Obligate cave fauna of the 48 contiguous United States. *Conservation Biology* 14:386-401.
- Culver, D. C. and T. Pipan. 2009. *The Biology of Caves and Other Subterranean Habitats*. Oxford University Press, New York, 254pp.
- Fisichelli, N. 2013. *Climate Change Trends, Mammoth Cave National Park, Kentucky*. Unpublished Report, 6pp.

- Fry, J. F. 1996. Eighteen cave gates and airlocks: conclusion of a three-year project to restore cave entrance dynamics at Mammoth Cave National Park in Mammoth Cave National Park's Fifth Science Conference, Mammoth Cave National Park, pp. 69-83.
- Helf, K. L. 2003. Foraging Ecology of the Cave Cricket *Hadenoeus subterraneus*: Effects of Climate, Ontogeny, and Predation. Ph.D. University of Illinois at Chicago, Chicago, IL, 170pp.
- Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, C. E. Konrad, II, C. M. Fuhrman, B. D. Keim, M. C. Kruk, A. Billet, H. Needham, M. Schafer, and J. G. Dobson. 2013. 2013: Regional climatic trends and scenarios for the U.S. National Climate Assessment. Part 2. Climate of the Southeast U.S., National Oceanic and Atmospheric Administration, 94pp.
- Lavoie, K. H., K. L. Helf, and T. L. Poulson. 2007. The Biology and Ecology of North American Cave Crickets. *Journal of Cave and Karst Studies* 69:114-134.
- Mosquin, P. L. and S. K. Thompson. 1998. Frame free adaptive designs in Online proceedings of the Survey Research Methods Section. American Statistical Association, pp. 431-436.
- Poulson, T. L. and K. H. Lavoie. 2000. The trophic basis of subsurface ecosystems in H. Wilkens, D. C. Culver, and W. F. Humphreys, editors. *Subterranean Ecosystems*. Elsevier, Amsterdam, pp. 231-249.
- Poulson, T. L., K. H. Lavoie, and K. L. Helf. 1995. Long-term effects of weather on the cricket (*Hadenoeus subterraneus*, Orthoptera, Rhaphidophoridae) guano community in Mammoth Cave National Park. *The American Midland Naturalist* 134:226-236.
- Poulson, T. L., K. H. Lavoie, and K. L. Helf. 2000. NRPP Entrance Monitoring Final Report. National Park Service, Mammoth Cave, KY.
- Riley, R. H. and R. L. Jefferies. 2004. Subsidy dynamics and global change in G. A. Polis, M. E. Power, and G. R. Huxel, editors. *Food webs at the landscape level*. The University of Chicago Press, Chicago, IL, pp. 410-433.
- Salehi, M. M. and G. A. F. Seber. 2013. Adaptive sampling designs: inference for sparse and clustering populations. Springer, Heidelberg, Germany, 70pp.
- Schneider, K. 2009. How the availability of nutrients and energy influence the biodiversity of cave ecosystems. University of Maryland, College Park, 174pp.
- Studier, E. H., W. D. I. Wares, K. H. Lavoie, and J. A.-M. Linn. 1987. Water budgets of cave crickets, *Hadenoeus subterraneus* and camel crickets, *Ceuthophilus stygius*. *Comparative Biochemistry and Physiology* 86A:295-300.
- Thompson, S. K. 2002. Sampling. Second edition. John Wiley & Sons, Inc., New York, NY, 367pp.
- Ver Hoef, J. M. and P. L. Boveng. 2007. Quasi-Poisson vs. negative binomial regression: how should we model overdispersed count data? *Ecology* 88:2766-2772.
- Young, B., E. Byers, K. Gravuer, K. Hall, G. Hammerson, and A. Redder. 2011. Guidelines for using the NatureServe climate change vulnerability index. NatureServe, Arlington, VA, 63pp.

The Effects of the Fungus *Beauveria sp.* on the Cave Cricket, *Hadenoeus subterraneus*

Christina Walker¹, Derrick Jent¹, and Claire Fuller¹

¹ Murray State University

Abstract

The cave cricket, *Hadenoeus subterraneus*, is a keystone species in cave ecosystems within Mammoth Cave National Park (MCNP). Within MCNP, many cricket cadavers have been found with a thick, white fungus growing on them; this fungus has previously been identified to be *Beauveria bassiana*. However, new molecular data suggests that this may actually be the species *B. amorpha*. Cricket cadavers with *Beauveria sp.* were collected from MCNP and cultured on potato dextrose agar. Cultures will be sent to the USDA for a genetic analysis and identification of the fungus. The purpose of this study is to examine if the relationship between the cave crickets and the fungus is of parasitic or saprophytic nature. Fifteen crickets will be exposed to a 1×10^6 conidia solution, while the other 15 will be exposed to a Tween-80 solution for the control group. Mortality rates will be observed daily and analyzed.

Citizen Science at Mammoth Cave National Park: Integrating Research and Education

Shannon R. Trimboli¹

¹ Mammoth Cave International Center for Science and Learning, Ogden College of Science and Engineering, Western Kentucky University

Introduction

Citizen science is a phrase used to describe partnerships between the public and professional scientists to conduct scientific research. Citizen science projects have existed for centuries and have been called many different names including volunteer monitoring, public participation in scientific research (PPSR), crowd-sourced science, and research by amateur naturalists. Citizen science projects can cover a wide variety of topics including microbiology, ecology, geology, hydrology, meteorology, history, and public health to name a few.

In 2012, the National Park Service identified citizen science as a way of creating and engaging the next generation of park researchers and stewards in *A Call to Action: Preparing for a Second Century of Stewardship and Engagement*. In 2015, the Citizen Science Association was founded as the first professional organization focused on the field of citizen science. In 2016, the National Science Foundation made citizen science and related forms of public participation in scientific research a funding priority. Public interest in participating in citizen science projects both inside and outside of the traditional classroom has also rapidly increased in recent years.

The Mammoth Cave International Center for Science and Learning (MCICSL), a partnership between Western Kentucky University (WKU) and Mammoth Cave National Park (MCNP), has actively built a strong citizen science program at MCNP. The goal of MCICSL's citizen science program is to integrate research and education. To achieve this goal, each project under the citizen science program teaches the participants about the resources being studied, while also providing

resource managers and/or researchers with scientifically valid data they would not otherwise be able to collect.

MCICSL's citizen science program at MCNP encompasses a wide range of research projects to appeal to a wide variety of audiences and helps meet MCNP's numerous



Figure 1: High school interns with The Nature Conservancy collect data for a water discharge citizen science project at Mammoth Cave National Park.

research and monitoring needs. The scope of the citizen science program includes projects focused on both natural and cultural resources and projects that occur both in the caves and on the surface (Figures 1 - 4).

Participant engagement covers a wide spectrum. At one end of the spectrum, participants simply collect data that is sent to a professional scientist. At the other end of the spectrum, the participants are primary investigators on the research permit and participate in all aspects of the scientific process. Tables 1 and 2 summarize the MCNP-based citizen science program developed by MCICSL.

Accomplishments

MCICSL's citizen science program at MCNP has grown from a single citizen science project in 2009 to 11 park-based citizen science projects today. Since funding for the program was received in 2012, almost 900 individuals have participated in the citizen science program as of March 15, 2016. Those

individuals have contributed approximately 5,700 hours of volunteer work equivalent to over \$132,000 in labor.

The data collected and research conducted by the citizen scientists add additional value to the program because each citizen science project is designed to provide scientifically valid data that MCNP resource managers and/or partnering researchers would not otherwise be able to collect.

The majority of program participants are middle school through college students. MCICSL's citizen science program provides unique opportunities for the students to learn about the park's resources, gain in-depth research experience, and make a valuable contribution through their work. Through the citizen science program, MCNP creates deep connections between the participants and the park, fosters the next generation of resource stewards, and sponsors excellence in scholarship while increasing the park's knowledge and ability to make science-informed decisions.

By integrating education, research, and stewardship, MCICSL's citizen science program supports 12 action items identified in *A Call to Action* and is creating the next generation of park visitors, stewards, supporters, and advocates.

The citizen science program is a model for other parks wanting to start park-based citizen science projects. Each year, several parks contact MCICSL's education coordinator for expert advice and guidance on establishing citizen science projects. MCICSL's education coordinator has presented at several conferences and workshops on ways to effectively integrate citizen science into park resource management programs. The lead researchers for many of MCNP's individual citizen



Figure 2: Middle school students from Edmonson County Middle School have a citizen science project conducting wood frog and early-breeding salamander egg mass surveys at Mammoth Cave National Park.

science projects have also given their own presentations about their projects and the results of the citizen science-based research.

Challenges and Opportunities

The citizen science program developed by MCICSL has faced and continues to face many challenges. There are also many exciting opportunities for the program. The two most significant challenges and the two greatest opportunities are discussed below.

The largest challenge for the program is a lack of secure and reliable funding. MCICSL and the citizen science program it has developed for MCNP are grant and project funded. Funding for MCICSL to develop and implement MCNP's citizen science program came through an NPS fee project that MCNP received in FY12. New funds to continue and grow the citizen science program were requested, but were not approved. Without additional funding, the citizen science program will end in 2017 when the current funds run out.

The second largest challenge for the MCNP-based citizen science program is also its greatest and most exciting opportunity. Interest in the citizen science program has increased significantly over recent years. That interest continues to grow among teachers wanting to involve their students in the citizen science projects and among researchers / resource managers wanting to develop citizen science projects to support their work. The interest in and demand for these programs indicates significant opportunities for growing and expanding the citizen science program.

Unfortunately, current demand far exceeds MCICSL's capacity to meet that demand. In addition to developing and implementing the citizen science program at MCNP, MCICSL is also responsible for leading most of the



Figure 3: Honors students at Northern Kentucky University are inventorying, photo-documenting, and assessing the condition of Civilian Conservation Corps (CCC) artifacts used in trail building at Mammoth Cave National Park as part of a cultural resources-based citizen science project.

classes participating in the citizen science projects. MCICSL's staff consists of two people – a research director and an education coordinator. The education coordinator is the primary person responsible for developing, implementing, and leading the citizen science program. Both the education coordinator and the research director have other duties in addition to those associated with the citizen science program.

Only the passion of MCICSL staff and their partners has allowed the citizen science program to grow to its current capacity, but passion and dedication can only take a program so far. Currently, both researchers wishing to create new citizen science projects and classes wishing to participate in the citizen science projects are being turned away due to a lack of capacity.

Teachers and researchers / resource managers are not the only ones interested in the citizen science program. In addition to simply growing and expanding the current citizen science program focused on participation by middle school through college students, an opportunity exists to grow the citizen science program in a new direction that incorporates a new audience.

Members of the public have also expressed interest in participating in citizen science projects at MCNP either as individuals or as families. This public interest indicates an additional new opportunity for growth if solutions are found to the current funding and capacity issues facing the program.

Conclusions

Over the past five years, MCICSL has developed a strong, multi-disciplinary citizen science program for MCNP. The program provides a rare hands-on, interactive, experience that integrates research and education. Participants learn about the park's natural and cultural resources while gaining experience conducting research and making a valuable contribution to MCNP's research and resource management needs.

Researchers and resource managers benefit from the program by gaining access to data that they would not otherwise have the resources to collect. By integrating educational, research, and stewardship opportunities while reaching out to diverse audiences, the MCICSL-developed citizen science program strongly supports four of the NPS Centennial Goals and supports a dozen action items listed in *A Call to Action*.

Researchers and resource managers are actively seeking out MCICSL staff to inquire about opportunities to incorporate citizen science into their work. Teachers

and professors continue to contact MCICSL staff about opportunities to participate in current citizen science programs or to develop citizen science projects in which their students are the primary investigators. Members of the public have also inquired about opportunities to participate in citizen science projects as individuals or as families indicating a new opportunity and direction for growing the program.

Although the program has been successful, it faces two significant challenges that have the potential to severely affect the program's future. Those challenges are a lack of funding and a lack of staffing to meet program demand. If solutions to those two challenges are found, then the program has significant opportunity to grow and expand while continuing to support MCNP's research, resource management, education, and interpretation goals.



Figure 4: Middle school students collect dragonfly larvae for a multi-park citizen science project studying mercury levels in dragonfly larvae.

Table 1: Citizen science projects where citizen scientists are the lead researchers and permit holders.

Project	Citizen scientists	Primary research goal	Importance	Year started	Status
Monitoring the reverse flow patterns of the River Styx	T.K. Stone Middle School, 7th grade students	Gather baseline data on the frequency and duration of the River Styx's reverse flow events and the temperature ranges of the River Styx, Echo River, and Green River.	Reverse flow events change the water temperature in the River Styx and bring additional nutrients into the cave, which can impact the animals living in River Styx. Changes in water temperature, especially during the winter, can also create condensation or fog in the cave. The condensation and fog can affect the formation of geological features and increase fungal growth on archeological or cultural artifacts.	2009	Wrapping-up
Wood frog and salamander egg mass surveys	Edmonson County Middle School, 7th and 8th students	Compare the park's current wood frog and early breeding salamander populations to the populations reported in a similar study from the 1990s.	Amphibians are highly susceptible to climate change and other local environmental changes. Since the 1990s project concluded, climate change has continued, traffic near the surveyed ponds has increased, and management strategies such as the use of brine on the roads during winter storms have changed. All of these factors could have an impact on the populations of wood frogs and early breeding salamanders.	2012	On-going
New Discovery Cultural Resource Inventory and Condition Assessment	Northern Kentucky University's Honors Program	Map, photo-document, and assess the condition of CCC artifacts in New Discovery.	The artifacts left in New Discovery by the CCC provide unique insights into the CCC and cave trail development at MCNP. While the stable cave environment provides a level of protection and preservation for the artifacts, some deterioration is occurring, especially in wetter areas of the cave. Documenting and assessing condition of the artifacts will provide the park with a better understanding of the current condition of the resources.	2014	On-going
Monitoring underwater natural and cultural resources	Mercy Academy, high school students	Expand existing knowledge about the natural and cultural resources in the park's underground rivers by using a remotely operated submersible to increase accessibility.	Cave diving is difficult, dangerous, and requires a highly specialized skill set. Because of this, much is unknown about the natural and cultural resources found in MCNP's underground rivers. This study will provide park resource managers with a better understanding of the natural and cultural resources found in the park's underground rivers.	2015	On-going

Table 2: Citizen science projects where the primary role of citizen scientists is to collect data. In all cases, most of the citizen scientists are middle school through college classes working with MCICSL.

Project	Primary research goal	Importance	Year started	Status
Cave water discharge	Collect additional data for USGS / Tennessee State University partner on how fast the water is flowing at various locations in the cave at different times of the year.	Parking lot runoff, roadway runoff, sewer spills, and other water quality issues can result in contaminants entering the cave's aquatic ecosystems. How quickly those contaminants arrive at specific locations in the cave can vary due to precipitation patterns and weather events. A USGS / Tennessee State University researcher is developing a mathematical model for predicting how quickly contaminants could enter certain areas of the cave.	2012	On-going
Monitoring mercury levels in dragonfly larva	Collect dragonfly larvae for mercury analysis by University of Maine and USGS Forest and Rangeland Ecosystem Science Center researchers.	When consumed, mercury accumulates in the body and can cause nerve damage. Organisms higher up in the food chain have increased risks of reaching toxic mercury levels due to the mercury they accumulate from the other organisms they consume. Researchers at the University of Maine and USGS Forest and Rangeland Ecosystem Science Center are studying mercury levels found in dragonfly larvae at 53 National Parks.	2012	Wrapping up
Cave aquatic invertebrate monitoring	Gather baseline data on the population and diversity of aquatic invertebrates in the streams and pools associated with the water discharge project.	Many of the perched streams and pools associated with the cave water discharge project contain cave adapted aquatic invertebrates. Having baseline population information about those organisms could be useful if contaminants were to enter the system at those locations. The pools and streams in this study are not being surveyed as part of the Cumberland Piedmont Network's cave aquatic organism inventory and monitoring project.	2013	On-going
Mapping and documenting historic cemeteries at MCNP	Map and document condition of historic cemeteries.	MCNP has numerous historic cemeteries scattered throughout the woods. A study in the 1990s mapped and documented many of those cemeteries. Since then, the woods have continued to grow and the stones have continued to weather. By going back to map and document the cemeteries, this study provides a current assessment of the cultural resource. The project has also identified several headstones and inscriptions not documented on the MCNP Cemetery Database.	2013	Field-testing

Table 2: Continued

Project	Primary research goal	Importance	Year started	Status
Photo-monitoring of structures and locations in the cave	Create a visual reference of historic structures and locations in the cave that can be compared to older photographs to document changes over time.	MCNP resource managers often need to know when a structure such as a wall or staircase was installed or when something else changed at a historic location in the cave. These changes are not as well documented as one might anticipate. Finding historic photographs of a site and then taking periodic pictures from the same basic angle provides a quick, visual reference indicating the period of time during which any changes occurred.	2013	Field-testing; may not continue development
Project Budburst	Collect data on plant phenology at MCNP.	Climate change is causing some plants to bloom or leaf out earlier; however, the change is not uniform throughout the plant kingdom or across the globe. Project Budburst is an online, national citizen science project studying how climate change is affecting the phenology of plants. Data collected at MCNP can be used to study climate change at local and national scales.	2014	On-going
Mapping of CCC camp remains	Document and map the remains of MCNP's CCC camps.	The major CCC camp infrastructures were dismantled and removed when MCNP was established. However, artifacts still remain at most of the camps. These artifacts are subject to weathering and anthropogenic factors. Documenting and mapping existing artifacts will provide the park with a better understanding of the current condition of these resources.	2015	Field-testing

Undergraduate Research Projects Help Promote Diversity in the Geosciences

De'Etra Young¹, Shannon Trimboli², Rickard Toomey, III³, and Thomas Byl^{1,4}

¹ College of Agriculture, Tennessee State University

² Mammoth Cave International Center for Science and Learning, Ogden College of Science and Engineering, Western Kentucky University

³ Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park

⁴ Lower Mississippi-Gulf Water Science Center, U.S. Geological Survey

Introduction

A workforce that draws from all segments of society and mirrors the ethnic, racial, and gender diversity of the United States population is important. The geosciences (geology, hydrology, geospatial sciences, environmental sciences) continue to lag far behind other science, technology, engineering and mathematical (STEM) disciplines in recruiting and retaining minorities (Valsco and Valsco, 2010). A report published by the National Science Foundation in 2015, “Women, Minorities, and Persons with Disabilities in Science and Engineering” states that from 2002 to 2012, less than 2% of the geoscience degrees were awarded to African-American students. Data also show that as of 2012, approximately 30% of African-American Ph.D. graduates obtained a bachelor’s degree from a Historic Black College or University (HBCU), indicating that HBCUs are a great source of diverse students for the geosciences. This paper reviews how an informal partnership between Tennessee State University (a HBCU), the U.S. Geological Survey, and Mammoth Cave National Park engaged students in scientific research and increased the number of students pursuing employment or graduate degrees in the geosciences.

The student projects focused on water resources in a karst terrain and included a wide range of research topics including, parking lot runoff and filter efficiency, groundwater recharge and chemical transport, quantitative tracer studies, karst hydrology model development, geophysical logging, emergency spill response, geochemistry and geomicrobiology (Bradley, et al., 2011; Byl, et al., 2014; Painter et al., 2013; Brown, et al., 2015). These projects used a variety of tools and methods, including field data collection, geographic information systems, chemical and biological analysis, hydrologic instrumentation, modeling and experimentation.

Results of Student Engagement in Karst Research

Tennessee State University (TSU) is a land-grant university offering 45 bachelor’s degrees, 24 master’s degrees and 7 Ph.D. degrees, located in Nashville, Tennessee, United States. While TSU does not offer a geoscience degree, it has several degrees that introduce concepts about the earth and environmental sciences, such as environmental engineering, agriculture and environmental sciences, biology and chemistry degrees.

Twenty-two students (12 male, 10 female) participated in karst research projects from 2007 to 2015. They represented majors in environmental engineering, mathematical,

chemical and biological sciences. Each student interpreted data collected as part of their research and presented their results at a regional or national conference.

Of the 22 student researchers, three are still undergraduates, two accepted jobs after graduating with a bachelor's degree, 16 went on to masters programs with thesis projects that emphasized earth-science themes, and four students continued into Ph.D. programs (three geoscience majors and one physics major). Of the fourteen students that have completed their academic studies as of May, 2015, ten are currently employed in the geoscience or environmental engineering profession.

When the ten students were asked what influenced them to pursue a career in the geoscience profession, the overwhelming response was their research experiences that allowed them to collaborate with earth and environmental scientists. The student's research experience showed them the importance of water resource studies and environmental studies in helping to solve real-world environmental problems.

The research opportunities and professional meetings also provided an opportunity for the students to learn of employment opportunities, make professional connections, and feel like they could make a difference pursuing a career in geosciences. Another benefit of the student research was the financial assistance, which reduced the need to work off campus.

The benefits of experiential learning through undergraduate research go far beyond developing research methods skills. The outcome for these 22 students support the findings that structured research with faculty or professional geoscientists help students develop cognitive skills, strengthen personal and professional relationships, and improve

retention and enhance graduate school aspirations (Haak, et al., 2011; Freeman, et al., 2014). A series of STEM learning models developed by the National Research Council (2005) recognize several key components to successful student learning:

- 1) Learning and doing are inseparable (Cantwell, 2004). For example, calculating storm runoff from a parking lot or discharge in a cave stream enabled students to “learn science by doing science” (Figure 1).
- 2) Students learn in deep and enduring ways when they are actively engaged in authentic, real-world project-based problem solving (King et al., 2006). For example, organizing and interpreting large datasets from in situ monitoring equipment provided a lasting impression through real-world applications (Figure 2).



Figure 1: A TSU student setting up a storm monitoring station at the Mammoth Cave National Park Post Office parking lot. (Photo taken by T. Byl, U.S. Geological Survey, 2012)



Figure 2: A TSU student downloading data from a monitoring device as part of a tracer study that examined flow from the surface into the caves. (Photo taken by T. Byl, U.S. Geological Survey, 2015)

- 3) Inquiry-based educational materials (such as problem-based learning modules and case studies) are effective in improving student learning, attitudes, and interests (Michaelson et al., 1996). In this partnership, students applied methods from three previous studies (Mull et al., 1988; Fields, 2002; Palmer, 2007) to conduct quantitative dye studies conducted throughout Mammoth Cave National Park (Figure 3).
- 4) The students were able to move beyond the class room and experience the scientific method (theory, experimental design, instrumentation, measurement and data collection, data analysis, and presentation) in a real-world setting. This approach is a substantial pedagogical building block that stimulates and retains students, and prepares them well for their professional careers.

Students from TSU were encouraged to consider the issues that were posed by

employees from the USGS and Mammoth Cave Learning Center, develop a study plan, work with their mentors to implement the plan, and present the results at an appropriate forum (Figure 4).

Our experiences support findings presented by Villarejo et al. (2008) that undergraduate research experiences also played an important role in student career exploration and career choice. Lopatto (2007) conducted a survey of undergraduate research experiences and found that over 83% of the 1,135 students who participated in undergraduate research programs began or continued to plan for postgraduate education.

Laursen et al. (2010) describe in their book on undergraduate research in the sciences how students perceived their learning to be greater through research than through ordinary classes. Students reported increased technical skill, self-confidence, communication skills, and insight into



Figure 3: A National Park Service scientist and a TSU student prepare a simple dye-release system for a tracer study. (Photo taken by T. Byl, U.S. Geological Survey, 2011)

advanced study and career possibilities. The improved self-esteem and competence also translated to improved student persistence and retention.

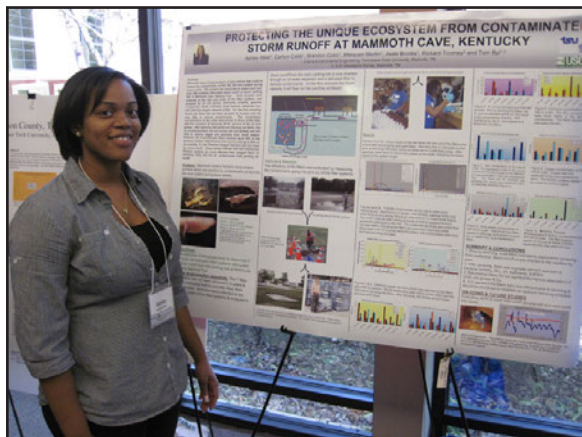


Figure 4: A TSU student presenting her award winning storm-water research at the Tennessee chapter of American Water Resources Research. (Photo taken by T. Byl, U.S. Geological Survey, 2013)

Conclusions

The informal partnership between TSU, the USGS, and the Mammoth Cave National Learning Center is helping to increase diversity in the geosciences through research experiences and professional development. As energy, climate change, water resources, and other earth-science issues become increasingly complex during the 21st century, geoscientists will encounter more difficult problems.

The future success of the geoscience community to help society understand and interact with the Earth system will depend on a diverse geoscience workforce that has insight into topics of concern for race, ethnicity, gender and cultural groups. Institutions must implement programs to increase minority participation in earth science disciplines, increasing the United States' cultural balance and global competitiveness in the coming decades.

In the next 10 years, the jobs available to college graduates will demand STEM skills and knowledge. Recruiting and retaining students with strong academic achievements through real-world geoscience projects becomes the first step in producing college graduates with these necessary skills (Huntoon and Lane, 2007; Murray et al., 2012). A diverse geoscience workforce is essential to helping society understand and respond to increasingly complex geoscience issues, especially with regards to topics of concern for different racial, ethnic and cultural groups.

Acknowledgements

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References

- Bradley, M.W., Armstrong, P., and Byl, T.D., eds., (2011), Partnership in Environmental Education and Research—A compilation of student research, 1999–2008: U.S. Geological Survey OFR 2010–1291, 67 p. <http://pubs.usgs.gov/of/2010/1291/pdf/ofr2010-1291.pdf>
- Brown, J.T.; Olson, R.; Solomon, D.; Sharpe, L., Jr; Toomey, R., III; Byl, T.D. (2015) Quantitative Tracer Studies at Mammoth Cave National Park with Implications for Contaminant Transport. In Proceedings from the 24th Tennessee Water Resources Symposium, Montgomery Bell State Park, TN, USA, April 2015, pp. P5. Available at: <http://tnawra.er.usgs.gov/Library/Proceedings.html>.

- Byl, T.D.; Metge, D.W.; Agymang, D.T.; Bradley, M.; Hileman, G.; and Harvey, R.W. (2014) Adaptations of indigenous bacteria to karst aquifers contaminated with fuel in southcentral Kentucky. *Journal of Cave and Karst Studies*, v. 76, no. 2, p. 104–113. DOI: 10.4311/2012MB0270 Available at: <https://caves.org/pub/journal/PDF/v76/cave-76-02-104.pdf>
- Cantwell, L.B. (2004) A Comparison of Learning: Integration of a Virtual and Traditional Field Trip into an Introductory Environmental Geology Course. Masters Thesis, Montana State University, Bozeman, Montana, November 2004. Available at: <http://scholarworks.montana.edu/xmlui/bitstream/handle/1/1038/CantwellL1204.pdf?sequence=1&isAllowed=y>
- Fields, M., (2002) The Q-Tracer2 Program for Tracer-Breakthrough Curve Analysis for Tracer Tests in Karstic Aquifers and Other Hydrologic Systems. U.S. Environmental Protection Agency report EPA/600/R-02/001. National Center for Environmental Assessment, Washington, D.C.
- Freeman, S.; Eddy, S.L.; McDonough, M.; Smith, M.K.; Okoroafor, N.; Jordt, H.; Wenderoth, M.P. (2014) Active learning increases student performance in science, engineering, and mathematics. *Proc. National Acad. Sci.* 111:8410-8415.
- Haak, D.C., HilleRisLambers, J., Pitre, E., Freeman, S. (2011) Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology. *Science* 332:1213-1216
- Huntoon, J.E.; Lane, M.J. (2007) Diversity in the Geosciences and Successful Strategies for Increasing Diversity. *Journal of Geoscience Education*, 55: 447-457
- King, L., & Painter, R., & Byl, T. (2006, June), Research Approach To Teaching Groundwater Biodegradation In Karst Aquifers. Paper presented at 2006 Annual Conference & Exposition, Chicago, Illinois. <https://peer.asee.org/953>
- Laursen, S.; Hunter, A.B.; Seymour, E.; Thiry, H.; Melton, G. (2010) Undergraduate Research in the Sciences – Engaging Students in Real Science. Published by Jossey-Bass, A. Wiley Imprint, San Francisco, CA. ISBN 978-0-470-22757-2
- Lopatto, D. (2007) Undergraduate Research Experiences Support Science Career Decisions and Active Learning. *CBE—Life Sciences Education*, 6:297–306
- Michaelsen, L. K.; Fink, L. D.; and Black, R.H., (1996) What Every Faculty Developer Needs to Know about Learning Groups to Improve the Academy. Paper 361. Available at: <http://digitalcommons.unl.edu/podimproveacad/361>
- Mull, D.S., Liebermann, T.D., Smoot, J.L., Woosley, Jr., L.H., Mikulak, R.J., (1988) Application Of Dye-Tracing Techniques For Determining Solute-Transport Characteristics Of Ground Water In Karst Terranes. EPA904/6-88-001, Atlanta, GA
- Murray, K.S.; Napieralski, J.; Luera, G.; Thomas-Brown, K.; Reynolds-Keefer, L. (2012) Broadening Diversity in the Geosciences Through Teacher–Student Workshops That Emphasize Community-Based Research Projects, *Journal of Geoscience Education*, 60:179–188
- National Research Council. (2005). *How Students Learn: Science in the Classroom*. Committee on How People Learn, A Targeted Report for Teachers, M.S. Donovan and J.D. Bransford, Editors. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press

- National Science Foundation. (2015) Women, Minorities, and Persons with Disabilities in Science and Engineering, 2015. National Center for Science and Engineering Statistics Directorate for Social, Behavioral and Economic Sciences. Report 15311. Available at: <http://www.nsf.gov/statistics/2015/nsf15311/digest/nsf15311-digest.pdf>
- Painter, R., Embry, I., Roland, V., Toomey, R., Sharpe, Jr., L., Byl, T.D. (2013) An Alternative to the Advection Dispersion Model for Interpreting Dye Tracing Studies in Fractured-Rock and Karst Aquifers. In S. Trimboli ed., Proceedings of 10th Mammoth Cave Science Symposium, pg 99-102. available <http://brimsbg.org/wp-content/uploads/2013/02/Symposium-Proceedings.pdf>
- Palmer, A.N. (2007) Cave exploration as a guide to geologic research in the Appalachians. *Journal of Cave and Karst Studies*, 71:180–192
- Velasco, A.A., and Velasco, E.J., (2010) Striving to Diversity the Geoscience Workforce. in *Transactions American Geophysical Union*, 91:289–290
- Villarejo, M.; Barlow, A.E.L.; Kogan, D.; Veazey, B.D.; and Sweeney, J.K. (2008) Encouraging Minority Undergraduates to Choose Science Careers: Career Paths Survey Results. *CBE—Life Sciences Education*, 7:394–409

Youth Engagement in Public Health at Mammoth Cave National Park: A Pilot Alternative Spring Break Program

Laura Shultz¹, David Wong², Amy E. Thomas³, Rick Toomey⁴, and Shannon Trimboli⁵

¹ Student Conservation Association, Mammoth Cave National Park

² Epidemiology Branch, National Park Service Office of Public Health

³ Mammoth Cave National Park

⁴ Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park

⁵ Mammoth Cave International Center for Science and Learning, Ogden College of Science and Engineering, Western Kentucky University

Abstract

Each year, students from over 200 colleges and universities participate in Alternative Spring Breaks (ASBs) — volunteer, service-oriented missions that empower youth to become active citizens. Since 2000, at least 25 National Park Service (NPS) units have hosted ASBs where students volunteered to build trails, remove invasive plants, and provide other needed services (Nelson 2016). While such programs successfully connected youth with parks, particularly those interested in conservation, ASBs are also an opportunity to introduce students to the myriad and diverse career paths within NPS.

Description of Pilot Alternative Spring Break Program

During February 28 - March 4, 2016, Mammoth Cave National Park (MACA) and the Mammoth Cave International Center for Science and Learning partnered with the NPS Office of Public Health to host a pilot ASB program focused on public health. Through direct, hands-on service, seven students and one professor from Alma College in Michigan spent a week learning about park-specific public health issues, including rabies, rodent-borne diseases, and recreational water quality. Issues were framed using a One Health perspective, which recognizes that the health of people, animals, and our environment are inter-connected and are best addressed using an inter-disciplinary approach.

ASB activities included monitoring bat populations on tour routes to better understand risk for bat-human contacts; performing rodent exclusion on seasonal housing; collecting and testing cave water for *E. coli* contamination; and building and setting traps for ticks and Asian lady beetles. For more information on each activity,

see Figure 1. Students received 1-1.5 hours of lecture/training each day, interacted with park staff from multiple divisions, and learned about career opportunities in NPS, public health, or both. Proper personal protective equipment (PPE) was used during all activities.

Benefits to the National Park Service

In *A Call to Action*, the NPS commits to “*strengthen the Service as an education institution and parks as places of learning that develop American values, civic engagement, and citizen stewardship.*”

Partnering with the ASB program at Alma College is a natural extension of this idea.

This pilot program capitalized on both education and service to truly impact the participating students. By engaging in participatory learning and fostering transformative experiences as outlined in *Achieving Relevance in our Second Century, A Five-year Strategy for Interpretation, Education, and Volunteers as We Enter the Second Century of the National Park*

Service, we are using proven techniques that are primed to propel the Service forward.

The students worked with three divisions collaboratively (Resource Management, Interpretation, and Maintenance) and were exposed to multiple One Health disciplines, including environmental studies, public health, entomology, and hydrology. By participating in hands-on data collection and solutions to public health risks (such as

implementing rodent exclusion), students were able to take away a sense of pride in their accomplishments that connected them more strongly to their public lands and their contributions as citizen stewards.

Evaluation

Participating students were asked to complete a self-administered survey that assessed the effectiveness of both program






Activity	Public Health Risks	Summary of Actions	Impact of Actions
Asian Lady Beetle Light Traps 	Mental health of the employees in the afflicted offices as well as allergy concerns	Students built and placed light traps throughout park structures to eliminate invasive Asian lady beetles from work environments.	These were the first set of light traps to systematically attempt to eliminate the Asian lady beetle from park offices to be used by park employees.
Bat Monitoring Along Toured Cave Routes 	Bat-Human contacts and the potential for exposure to rabies	Students walked each of five tour routes each day in separate groups and monitored the bat population and activity on each route to assess risk of contacts.	This data collection assisted in park monitoring and understanding of bat behavior along routes of potential human exposure.
Coliform Samples 	Exposure to <i>E.coli</i> bacterium through water sources in the park	Students split into groups and collected, processed, and analyzed water samples throughout the park for a snapshot of <i>E.coli</i> conditions.	This snapshot of <i>E.coli</i> load throughout the park gives the park a better knowledge of water quality conditions.
Rodent Exclusion 	Potential exposure to rodent borne diseases, including hantavirus	Students performed building maintenance tasks to close rodent entry-points and exclude them from residential structures.	Rodent Exclusion work directly improved seasonal housing and decreased the risk of exposing residents to rodent-borne diseases.
Tick Collection with CO₂ Traps 	Exposure to Tick-borne diseases including lime disease, rocky mountain spotted fever, etc.	Students built and placed CO ₂ traps throughout the park to monitor populations and collect samples for testing.	This was the first tick monitoring during the winter at Mammoth Cave, adding to the park's knowledge of tick population and behavior throughout the year.

Figure 1: Alma College students participating in the public health Alternative Spring Break program assisted the park with five monitoring and abatement projects focused on public health issues. This chart summarizes those activities and their results. Proper PPE was used during all activities.

implementation and impact. The survey was administered at the beginning of the program prior to the planned activities and at the end before the group's departure.

Initial analysis of the evaluations indicates a high level of success. The average level of student satisfaction with the training, facilities, diversity of projects, and relevance of the completed projects all rated between 4.75 and 4.88 on a 1.00 to 5.00 scale, with 5.00 being the highest. When asked about several specific knowledge, skills, and abilities taught throughout the programming, there was an overall 40% increase in comfort level across the various projects and their related tasks in the post-program responses compared to the pre-program responses.

In one question, students were asked to rank the likelihood of considering a career in the NPS; compared to the pre-program responses, there was a 31.6% increase in the post-program responses. There was an 8.9% increase in the post-program responses when asked if the students would consider a career in public health; however, the responses were relatively high in both cases, increasing from an average likelihood of 3.88 to 4.25 on the same scale.

This pilot program successfully showcased the breadth of public health activities conducted in parks, highlighted the potential for ASBs to introduce youth to new career opportunities within federal agencies, and set a foundation for subsequent programs in the future.

Several students agreed as evidenced by the following quotes:

"... a once in a lifetime experience... [I] am considering a career in the NPS now thanks to this trip."

"This was the most interesting and memorable break I've ever had, and I'm truly inspired to learn more about the parks, public health, public service, etc."

"This experience changed my outlook on my career path and made me realize what is and is not important. I learned so much and wouldn't trade this experience. Your passion is so inspiring."

Summary

Traditionally, student internships, such as NPS Academy and Centennial Volunteer Ambassadors, have been the primary tools for engaging youth with national parks. This pilot demonstrates that, with dedicated staff and effective programming, week-long ASBs can provide students with immersive experiences that highlight the diversity of park resources, all while introducing them to career opportunities. We plan to share the lessons learned from this pilot with other parks and other public health agencies. Similar career-specific ASBs could be developed at other NPS units and with other colleges.

Chronicling Mammoth Cave Data Visualization

Matthew Beckerich¹, Jared Koshiol¹, Noah Love¹, Greta Lowe¹, Celeste Shearer¹, and David Kime¹

¹ Honors Program, Northern Kentucky University

Abstract

The Library of Congress and the National Endowment for the Humanities (NEH) has created the *Chronicling America: Historic American Newspapers* database containing thousands of digitized newspapers dating from 1836 to 1922. This time is well-suited to research visitor experiences at Mammoth Cave, Kentucky. Students from the Honors Mammoth Cave course created an entry for a national competition to create a web-based data visualization showcasing the type of information and research available through the database. This presentation will highlight the results of student research and their final product.

Six Americas: Where Do Teachers Stand

Jeanine Huss¹ and Cheryl Messenger²

¹ School of Teacher Education, Western Kentucky University

² Mammoth Cave National Park

Abstract

Teachers spent two days at Mammoth Cave National Park learning about climate change and specifically how climate change could affect the animals and plants at Mammoth Cave National Park. Two surveys tested the teachers' understanding of climate change. The poster will share ideas about what to teach elementary and middle school teachers about climate change and the results from the two surveys given during the two day workshop.

Introduction

The Yale Project on Climate Change created a survey which tracks Americans' changing ideas about climate change. Their survey, *Global Warming's Six Americas*, placed people into six major groups: alarmed, concerned, cautious, disengaged, doubtful, and dismissive. The groups help explain why Americans split on the issue of climate change.

The alarmed group includes older, middle aged women who are college educated with an upper middle class income. They tend to want government to help all people. Moderate Democrats make up the concerned group. They focus on environmental protection over growth in the economy. The disengaged are moderate Democrats who prefer growth in the economy over the environment and are not active in politics. Less educated, lower income minority women make up the disengaged group. The doubtful group tends to be made up of male, older, better educated Republicans who have an average rate of involvement in politics. The dismissive are high income, well-educated white men who are conservative Republicans. Active in politics, they favor individualistic values and oppose government intervention.

The teachers at this workshop fit into these categories as well. The group of teachers in the Mammoth Cave workshop, because they self-selected the workshop, probably tend to be more interested in climate change, as a whole.

Survey of Workshop Participants

Teachers took the three tiered diagnostic test at the beginning and end of the workshop. The three-tiered diagnostic test (AREDiT) assessed teacher misconceptions about global warming, greenhouse effect, ozone layer depletion and acid rain showed many interesting results.

A t-test showed a significant result between pre and post scores of teacher knowledge at the start and end of the workshop. A chi-squared test of the different categories (scientific knowledge, misconception (false positive), misconception (false negative), misconception, lucky guess or lack of knowledge, lack of knowledge 1, lack of knowledge 2 and lack of knowledge 3) showed a p-value=0.004005. It was significant at the p=.05 level and highly significant at the p=.01 level.

This shows that the workshop did help teachers gain knowledge about topics dealing with climate change issues. They

reduced their lucky guesses from 19% to 9%. They also increased their scientific knowledge from 43% to 61%.

Workshop Description

The workshop, held mainly at the Mammoth Cave training center, taught concepts dealing with climate change to 3rd through 8th grade teachers. A focus on water initiated the workshop, which plays a vital part in the ecology of Mammoth Cave. As an icebreaker, participants tossed a globe beach ball, stating if their right thumb landed on water or land, while also stating their names and where they taught. This led into A Drop in the Bucket, also from Project WET, which examines the percent of water on the earth made up of salt water, glaciers, underground aquifers, and potable water. Teachers examined world water facts to better understand the importance of water from a global perspective.

Using Global Learning and Observations to Better the Environment (GLOBE), teachers brought cloud identification posters and cloud “windows” which allow you to look up at the sky to match the color of the sky and color of the clouds with colors around the window. A short NASA video discussed the difference between weather and climate followed the activities on water and clouds.

We determined teachers of primary students should teach concepts about weather and water to their students to better understand climate change in middle school. These activities helped set the foundation for other activities to come later in the workshop.

After lunch, a trip to River Styx provided a first-hand experience with cave critters and understanding the delicate nature of the cave. Water entering the cave brings in nutrients to animals who live in the water. An eyeless cavefish and crawfish at River

Styx only occur within certain temperatures of the water.

The second day, teachers learned how collecting data helps strengthen a scientists’ understanding of his/her research. After watching a NASA video on a warming world, teachers conducted climate change experiments created by NASA that showed how carbon dioxide can affect temperature, how sea ice affects temperature and how melting ice affects sea level rise. Rick Olson discussed how climate change could effect Mammoth Cave National Park, which emphasized the ecology of Mammoth Cave, both inside and outside the cave.

Another connection to Kentucky ecology derived from looking at how the number of trees affects climate change. Teachers measured trees outside and learned how the diameter at breast height (DBH) affects the amount of carbon dioxide absorbed by trees’ leaves. The type of tree and number of trees predicts the amount of carbon each tree could absorb. These activities came from Project Learning Tree (PLT) modules, PLT Focus on Forests and the Southeastern Forests and Climate Change.

An activity involving interpretation of graphs helped teachers understand how different scientific studies collect information on a small part of climate change. Correct interpretation of the graphs was the primary goal of this activity. The graphs also discuss a broad range of topics including biology, ecology, earth science and climatology.

Teachers wrapped up the workshop by presenting their new knowledge of climate change through skits. A few things to change about the workshop would include a smaller range of grades for teachers and helping teachers discuss what they have used in their classrooms in the past.

Drainage to Mammoth Cave National Park

Chris Groves¹, Katie Algeo², and Laura Myers^{1,*}

¹ Crawford Hydrology Lab, Western Kentucky University

² Dept. of Geography and Geology, Western Kentucky University

* Currently at Cosmos Cement

Abstract

Since land use is carefully managed within U.S. national parks, the most significant negative impacts to resources, including impacts to water quality, air quality, and from exotic species, often come from external sources. To identify water quality threats it is critical to define the region that drains to a park, as land use within that area is the principal source of water contamination. Compared to most national parks, determining drainage to Mammoth Cave National Park (MACA) is relatively complicated due to the highly developed karst landscape/aquifer system so integral to MACA.

While in general the area draining to MACA is well known (Meiman, 2005), we present here the most comprehensive single map so far developed of drainage to MACA (Figure 1), that for the first time includes corrections to areas of the catchment boundaries that were influenced by differences between those of the Hydrologic Unit Code (HUC) maps from the US Geological Survey (USGS) National Hydrography Dataset (NHD) and subsurface karst basin boundaries based on the Kentucky Geological Survey (KGS) Karst Atlas Maps (Osterhoudt, 2014).

NHD map catchment boundaries are based on surface topography, which can be misleading where drainage boundaries cross sinkhole plains in karst settings, as in areas of the Green River upstream from MACA (Figure 2). An extensive program of dye tracing over more than four decades (Currens and Ray, 1999) has provided the necessary flow data to make these corrections.

Four principal regions drain to MACA:

1) surface drainage from the Green River valley to the east, 2) surface drainage from the Nolin River valley to the north, 3) subsurface karst flow into the Green River from the south, and 4) subsurface karst flow into the Green River from the North. Green River surface drainage includes the river's floodplain crossing the karst sinkhole plain.

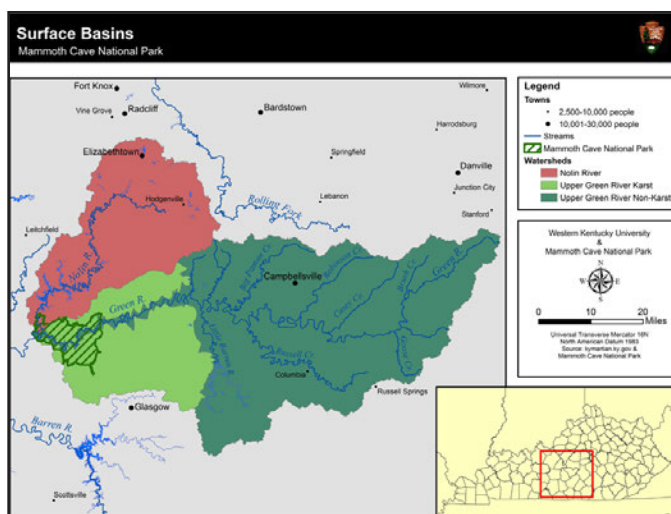


Figure 1: Map showing drainage areas upstream from Mammoth Cave National Park.

While land use in the MACA catchment is dominated by agriculture, it also includes urban areas of Elizabethtown and Campbellsville. One potential use of such a map is to provide a specific, quantifiable basis for the defined extents of the Zone of Cooperation and Outer Transition Zones for the UNESCO Mammoth Cave International Biosphere Reserve.

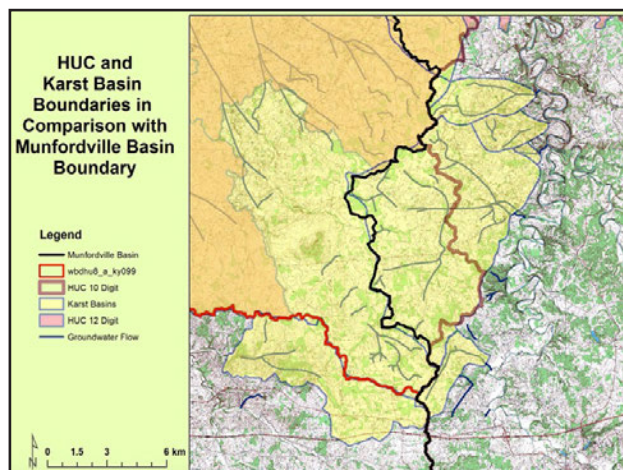


Figure 2: Map showing an example of basin boundary differences for the Green River Basin between those based on the USGS National Hydrography Data Set and those that consider subsurface karst flow as defined by the Kentucky *Karst Atlas Maps* (Currens and Ray, 1999). The brown line shows the basin boundary for the Green River based on the USGS HUC (Hydrologic Unit Code) 10, while the black shows the boundary based on the karst drainage. The area between the two is incorrectly attributed to the Green River on the USGS map, with a difference of nearly five km in places. Small differences between the boundary given by the karst atlas maps (blue) and the newly drawn boundary (black) reflect the slightly generalized nature of the line at the scale of the karst atlas maps.

References

Currens, J.C., & Ray, J.A. (1999) Karst atlas for Kentucky, in Beck, B.F., Pettit, A.J., & Herring, J.G., ed., *Hydrogeology and Engineering Geology of Sinkholes and Karst*, Proceedings of the 7th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, April 10-14, 1999, Harrisburg-Hershey, PA, Rotterdam, A.A. Balkema, p. 85-90.

Meiman, J., (2006) *Mammoth Cave National Park Kentucky Water Resources Management Plan* (2006). National Park Service, Mammoth Cave: Mammoth Cave National Park, 258 p.

Osterhoudt, Laura Leigh, (2014) *Impacts of Carbonate Mineral Weathering on Hydrochemistry of the Upper Green River Basin*, Kentucky. Masters Theses & Specialist Projects. Paper 1337. (<http://digitalcommons.wku.edu/theses/1337>)

Tracing Carbon in Karst Environments in South-central Kentucky to Identify Changes in Groundwater Dynamics under Varying Landuses

Chelsea Ballard¹, Jason Polk¹, and Kegan McClanahan¹

¹ Western Kentucky University

Abstract

In karst landscapes, the source, transport, and fate of carbon is of interest for several reasons, including the determination of carbon storage and release, contaminant transport, geochemical evolution of karst aquifers, global carbon budgeting, and cave evolution. As water moves from the surface to subsurface through the atmosphere, soil, and bedrock of a karst system, carbon isotopes can be used to “fingerprint,” or track, carbon, as well as provide insight to the potential changes and storage of carbon over time. Over a ten-month period, weekly rainfall, soil water (using lysimeters at two different depths), surface well water (shallow and deep), as well as water samples from an interior cave waterfall, were collected from an established cave research site, Crumps Cave, in south-central Kentucky for studying agricultural influences on groundwater dynamics. Samples were filtered, preserved, and analyzed for $\delta^{13}\text{C}_{\text{DIC}}$ values. Additional geochemical data were collected for each sample in the form of pH, SpC, temperature, and discharge and the amount of precipitation was collected at 10-minute resolution. Beginning March 2016, sampling will begin in and around Mammoth Cave to broaden the regional scale of sampling the karst system under differing conditions. Samples will also be analyzed for $\delta^{13}\text{C}_{\text{DIC}}$ values. Sample sites will include up stream River Styx spring and downstream Echo River spring, Green River, and a sample in the cave to look at the carbon flux and relationships between the two springs as they flow into the Green River. Comparisons will be made between the Crumps and Mammoth Cave sites to determine changes based on hydrology and landuse in similar hydrogeologic settings, but with varying influences. This information can be combined with other geochemical and hydrologic data to determine the role of carbon in the processes taking place that impact cave formation, groundwater evolution, and contaminant transport (nutrients, etc.).

Measurement of Inorganic Carbon Fluxes from Large River Basins in the South Central Kentucky Karst

Connor Salley¹ and Chris Groves¹

¹ Crawford Hydrology Lab, Western Kentucky University

Introduction

Atmospheric CO₂ concentrations are an important factor impacting current global climate change. As such, a greater understanding of the processes that govern atmospheric CO₂ fluxes is required in order to predict and potentially mitigate future climate change (Cox et al. 2000; Falkowski et al. 2000). Current carbon budgets do not sufficiently account for a substantial terrestrial sink of atmospheric CO₂ and therefore these budgets are unacceptably imprecise (Tans et al. 1990; Sundquist 1993; Fan et al. 1998). One of the processes that act as a sink of atmospheric CO₂ on the continents is weathering of carbonate rock minerals. While this sink is to some degree or perhaps wholly offset by carbonate mineral precipitation in the oceans, only a more precise accounting of the magnitudes of these fluxes will quantify the net effect.

Measurement of the CO₂ sink on the continents from carbonate mineral weathering involves two parts: 1) measurement of the inorganic carbon flux leaving a river basin over a given period of time and 2) partitioning that carbon between that having been removed from the atmosphere and that coming from the carbonate bedrock. While previous investigations have attempted to account for a terrestrial sink of atmospheric CO₂ by weathering of carbonate rocks (Figure 1) (e.g. Liu and Zhao 2000; He et al. 2012), this sink is still poorly characterized.

The purpose of this research is to improve methods for measuring the inorganic carbon flux from carbonate rock weathering at the river basin scale, so this carbon sink effect can potentially be more accurately characterized on a global scale.

This study made use of one year of existing, publically available water chemistry data and discharge data for two river basins along with geologic and hydrologic GIS data, and local precipitation and temperature

data. The total dissolved inorganic carbon (DIC) flux over a year for the Barren River upstream from Bowling Green (October 1, 2012-September 30, 2013), and the Green River upstream from Greensburg (February 1, 2013-January 31, 2014) were measured, and then normalized by time, water available for carbonate rock weathering (precipitation minus evapotranspiration (P-ET)), and the area of carbonate rock outcrop over each area.

We can simplify this by expressing the normalized fluxes as g C (km³ H₂O)⁻¹day⁻¹ (grams of carbon per cubic kilometer of water, per day) by multiplying the average depth of the available water (P - ET) by the area of carbonate rock outcrop. These normalized values have shown favorable comparison, and a positive linear relationship between total DIC and (km³ H₂O)⁻¹ day⁻¹ over the area of carbonate rock has been observed.

This linear relationship suggests, if it holds over a larger range of basin sizes and climates, that this flux could perhaps be

estimated over much larger areas without the direct use of water chemistry, or discharge data, and may be reduced to a Geographic Information Systems (GIS) technique involving only climatic and geologic data.

Methods and Results

Calculation of the DIC flux and normalization by depth of precipitation minus evapotranspiration over the carbonate rock area involved the use of water chemistry, discharge, geologic and hydrologic map data, and local precipitation and temperature data, all publically available and freely obtained. Calculation and normalization of this flux involved delineation of the drainage basin upstream from the sampling locations, determination of the area of geologic rock, estimation of average precipitation minus evapotranspiration over the basin, as well as the use of water chemistry and discharge data to measure the flux.

Data utilized to delineate the drainage area of the Barren River upstream from Bowling Green included US Geological Survey (USGS) Watershed Boundary Database (USGS WBD) data, Kentucky Geological Survey (KGS) Karst Atlas groundwater flow maps, and topographic maps. Accurate delineation of the drainage area is crucial to the final calculation of area of carbonate rock, and in carbonate rock dominated areas, subsurface flow can often strongly influence drainage and sometimes the locations of drainage divides.

The original USGS WBD drainage boundary for the Barren River was used as the starting point for delineation, but then karst flow that affected the locations of basin divides was taken into account using the KGS Karst Atlas maps. Groundwater sub basins identified as discharging

downstream from Bowling Green, or into a bordering drainage basin, were accounted for and removed (Figure 1) and the new drainage area was carefully delineated using topographic base maps. The drainage area upstream from Bowling Green with these corrections for karst influenced drainage divides was found to be 4247.7 km².

The area of carbonate rock was measured using the newly-delineated drainage basin. Geologic map data were obtained from the KGS Geospatial Data Gateway, and the USGS Mineral Resources Online Data Gateway. Using these map data, all formations classified as a limestone or dolostone according the Kentucky Geological Survey classification (as the majority of the drainage basin is in Kentucky, with a small amount in Tennessee) were selected. These formations were then combined into a single map layer using geoprocessing tools.

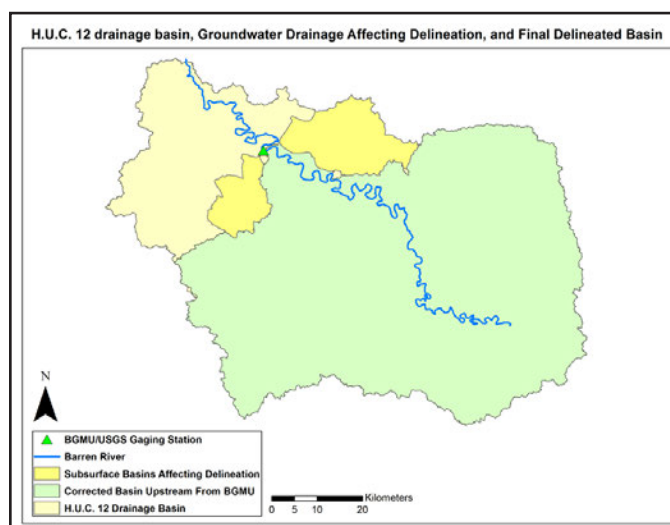


Figure 1: Barren River H.U.C 12 drainage basin, groundwater sub-basins affecting delineation, and delineated basin upstream from Bowling Green. Data sources: USGS WBD (2014); KGS (2014); USDA NRCS (2014).

The area of this final map layer was calculated, resulting in the area of carbonate rock within the drainage basin (Figure 2). The total area of carbonate rock within the basin was found to be 3995.5 km² or 94.1% of the drainage area. The area of carbonate rock for the Green River drainage basin upstream from Greensburg was obtained from Osterhoudt, (2014).

Precipitation and temperature data were obtained from the Kentucky Mesonet and the Midwest Regional Climate Center Cli-MATE Online Data Portal. Point precipitation data were obtained for stations in and surrounding the drainage basins. Potential Evapotranspiration (PET) was calculated using the Thornthwaite equation (Thornthwaite, 1948), and used to represent actual evapotranspiration (ET) during the study period. These monthly evapotranspiration values were subtracted from precipitation.

Final precipitation minus evapotranspiration ($P - ET$) values were interpolated in ArcGIS 10.1 using Inverse Distance Weighted (IDW) interpolation (Figure 3). Results from the IDW interpolation were compared to an identical data set but using Kriging methods, and the resulting total values agreed to within 0.52%. Average basin wide precipitation minus evapotranspiration over the drainage basins for each hydrologic year was 78.7 cm for the Barren River, and 66.7 cm for the Green River upstream from Greensburg.

Water chemistry data were provided by Bowling Green Municipal Utilities, for the Barren River at Bowling Green and by the Greensburg Water Works for the Green River at Greensburg. River stage data were provided by the US Geological

Survey for both locations, and discharge was also available from USGS for Bowling Green. River stage from Greensburg was used to develop a rating curve from existing National Oceanic and Atmospheric Administration (NOAA) data (Osterhoudt, 2014) to obtain discharge. Alkalinity,

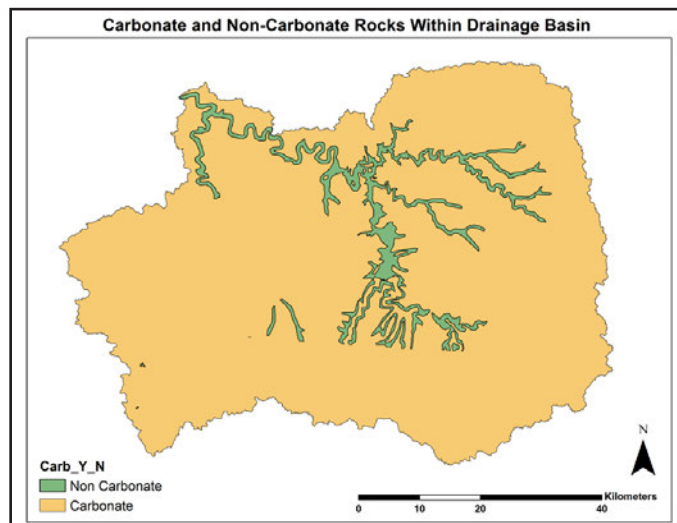


Figure 2: Carbonate and non-carbonate rocks within the drainage basin. Data Sources: KGS (2014); USDA NRCS (2014).

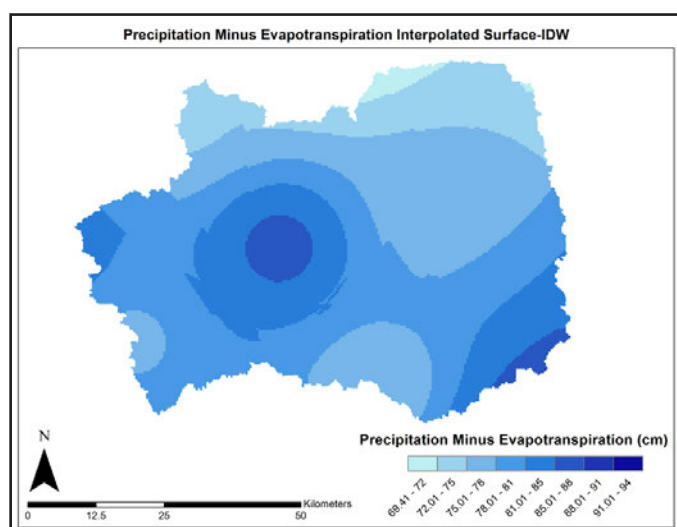


Figure 3: Annual precipitation minus evapotranspiration interpolated surface for the Barren River Drainage Basin using IDW. (Data Source: MWRCC, 2015).

pH, and temperature data had eight-hour resolution for Bowling Green, and daily resolution for Greensburg, while discharge data were of 15-minute resolution.

From the water chemistry data, DIC concentrations were calculated for each period of measurement, this value was multiplied by total volume of water discharged in each period, resulting in the total DIC flux. These flux values for each period of measurement were summed to find the total DIC flux for the year of study at both locations.

The total DIC flux was then normalized by time, in days, and volume of water available for carbonate rock dissolution, which is the product of the area of carbonate rock area and depth of P - ET. Resultant normalized values were of $5.61 \times 10^7 \text{ g C (km}^3 \text{ H}_2\text{O)}^{-1} \text{ day}^{-1}$ (grams of carbon per cubic kilometer of water, per day) for the Barren, and $7.43 \times 10^7 \text{ g C (km}^3 \text{ H}_2\text{O)}^{-1} \text{ day}^{-1}$ for the Green River.

Conclusions

Time and volume of water (carbonate rock area * (P – ET)) normalized DIC flux values for a year long of study for two separate basins were found to agree within 25%. Additionally, individual monthly normalized flux values were calculated for the year-long study period for the Barren River drainage basin.

When these twelve values are graphed along with the two for the Barren, and Green River hydrologic year values (Figure 4), the resultant r^2 value is 0.9495 which indicates a strong positive relationship between DIC flux and time-volume of water over carbonate rock.

This positive relationship indicates that the primary variables affecting DIC flux for these drainage basins, are time, and volume of water available for dissolution,

and that other potential variables may constitute much weaker inputs into the system.

These results show promise in the potential for estimation of DIC flux values over large areas using only climatic and geologic data. Future work in this area should include analysis of larger basins, and likewise normalization, to see if this trend continues with larger basins having varying area of carbonate rock and varying climate.

If this statistical relationship can be demonstrated over a larger range of basin sizes and climates, this will potentially allow for a much more accurate estimation of this carbon flux on a continental, or global scale. The ability to accurately estimate the magnitude of this sink effect over large areas without the direct use of water chemistry data could considerably contribute to the current understanding of this carbon sink

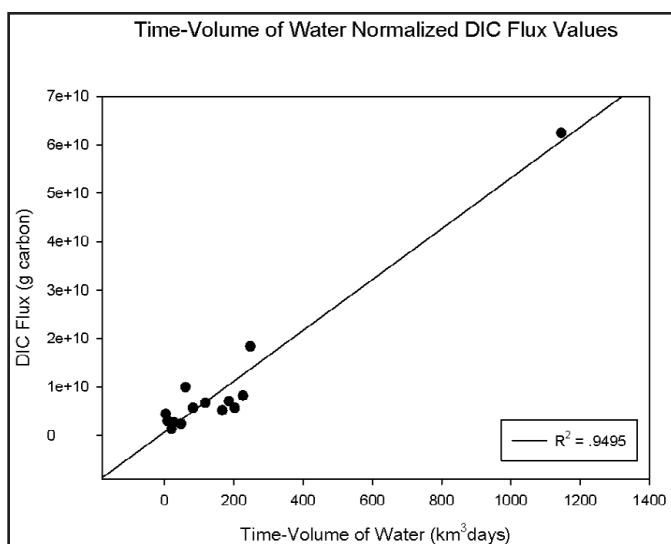


Figure 4: DIC flux versus time-volume of water available for carbonate rock dissolution, for the Barren, and Greensburg hydrologic years, and twelve months of the Barren hydrologic year. (Data sources: BGMU, GBWW, USGS)

effect and its magnitude on a global scale. This would result in more accurate carbon budgeting, potentially leading to a better understanding of the carbon sink currently un-accounted for by global carbon budgets (Liu & Zhao, 2000; Liu et al., 2011; White, 2013).

References

- Cox, P. M., Betts, R. A., Jones, C. D., & Spall, S. A. (2000). Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. *Nature*, 408(9 November), 184–187.
- Falkowski, P., Scholes, R. J., Boyle, E., Canadell, J., Canfield, D., Elser, J., Gruber, N., Hibbard, K., Hogberg, P., Linder, S., Mackenzie, F.T., Moore III, B., Pederson, T., Rosenthal, Y., Seitzinger, S., Smetacek, V., Steffen, W., (2000). The Global Carbon Cycle : A Test of Our Knowledge of Earth as a System. *Science*, 290(5490), 291–296.
- Fan, S., Gloor, M., Mahlman, J., Pacala, S., Sarmiento, J., Takahashi, T., & Tans, P. P. (1998). A Large Terrestrial Carbon Sink in North America Implied by Atmospheric and Oceanic Carbon Dioxide Data and Models. *Science*, 282(October), 442–446.
- Liu, Z., & Zhao, J. (2000). Contribution of carbonate rock weathering to the atmospheric CO₂ sink. *Environmental Geology*, 39(9), 1053–1058.
- Liu, Z., Dreybrodt, W., & Liu, H. (2011). Atmospheric CO₂ sink: Silicate weathering or carbonate weathering? *Applied Geochemistry*, 26, S292–S294.
- Osterhoudt, L. L. (2014). Impacts of Carbonate Mineral Weathering on Hydrochemistry of the Upper Green River Basin, Kentucky. Western Kentucky University.
- Sundquist, E. T. (1993). The global carbon dioxide budget. *Science*, 259(5097), 934–941.
- Tans, P. P., Fung, I. Y., & Takahashi, T. (1990). Observational constraints on the global atmospheric CO₂ budget. *Science*, 247(1431), 31–38.
- Thornthwaite, C.W. (1948). An approach toward a rational classification of climate. *Geographical Review*, 38(1), 55-94.
- White, W. B. (2013). Carbon fluxes in Karst aquifers : Sources, sinks, and the effect of storm flow. *Acta Carsologica*, 42(2-3), 177–186.

An Overview of the Reverse Flow Patterns of River Styx in Mammoth Cave, Kentucky: 2009-2012

Shannon R. Trimboli¹, Kim Weber², Susan Ryan³, and Rickard S. Toomey, III⁴

¹ Mammoth Cave International Center for Science and Learning, Ogden College of Science and Engineering, Western Kentucky University

² T.K. Stone Middle School, currently at Anderson County Middle School

³ Elizabethtown Independent School District

⁴ Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park

Introduction

One of Mammoth Cave's underground rivers is the River Styx. The River Styx flows out of the River Styx Spring and is a tributary to the Green River. The Green River is the primary surface river of the area. Under normal circumstances, the River Styx flows through Mammoth Cave and out the River Styx Spring where it discharges into the Green River. In the late 1950s, USGS scientists studying the Green River and its underground tributaries discovered a stable reverse flow pattern for the River Styx.

Under the stable reverse flow conditions, surface water from the Green River flows into the River Styx Spring and causes the River Styx to flow backwards. The backwards flowing River Styx flows into Echo River, another nearby underground river, and flows out of the Echo River Spring. Echo River Spring is located approximately 1.6 km downstream on the Green River from the River Styx Spring. This stable reverse flow condition is not a flooding event and occurs when the Green River is within its normal range of depths.

Understanding the River Styx's reverse flow patterns is important because the reverse flow events can affect the cave's climate, as well as directly affecting the cave's biological, geological, cultural, and archeological resources. Cave climate impacts include changes to the cave's air temperature, relative humidity, and condensation amounts. These climate impacts can extend significant distances away from the immediate location of the River Styx and cause additional impacts to

the natural and cultural resources found in those parts of the cave.

The timing and duration of the reverse flow events can be influenced by both natural (e.g. precipitation) and anthropogenic (e.g. releasing water from the Green River Dam, Lock & Dam 6) factors. Yet to our knowledge, little research beyond the USGS studies in the 1950s and 1960s has been conducted on the River Styx's reverse flow patterns.

In 2008, a 7th grade science teacher from T.K. Stone Middle School contacted the Mammoth Cave International Center for Science and Learning (MCICSL). She was interested in having her students conduct research at Mammoth Cave National Park. In the fall of 2009, T.K. Stone Middle School and MCICSL partnered to study the River Styx's reverse flow patterns.

Trimboli et al. 2011 provides details about the development of the project and lessons learned from conducting research with middle school students. This paper focuses

on a brief preliminary analysis of the data collected. A more in-depth paper and analysis is being prepared for publication at a later date.

Methods and Results

Students from T.K. Stone Middle School worked with MCICSL staff to collect water temperature data in the River Styx, Echo River, and Green River from October 2009 to October 2012. Water temperatures were collected every two hours using temperature data loggers. The data were used to determine the minimum, maximum, and mean temperature during the study for each river (Table 1).

Water temperature was also used as a proxy for determining the direction in which the River Styx was flowing. During reverse flow events, surface water from the Green River flows into the River Styx and changes its water temperature while Echo River maintains a stable temperature. During back-flooding events, the Green River floods into both the River Styx and Echo River, thus changing the water temperature of both underground rivers. The water temperatures for each river were graphed and the graphs were visually analyzed to determine patterns and identify reverse flow events.

Preliminary analysis of the graphs during times when data was available for all three rivers indicated that the River Styx was in a stable reverse flow condition 15 times and back flooded twice. Most of the reverse flow events occurred in December through March. Reverse flow events in spring and fall may be more difficult to identify using this study's methods because the Green River temperature tends to be closer to the

Table 1: Minimum, maximum, and mean temperatures in the River Styx, Echo River, and Green River from October 2009 to October 2012. Preliminary data.

	Mean Temperature	Maximum Temperature	Minimum Temperature
River Styx	13.5 °C + 2.5	23.8 °C	3.6 °C
Echo River	13.4 °C + 0.6	14.4 °C	9.2 °C
Green River	15.6 °C + 7.1	29.5 °C	1.3 °C

normal temperatures of the underground rivers. The duration of the stable reverse flow events appeared to vary from only a few days to several weeks.

Gaining a better understanding of the River Styx's reverse flow events is important because of the impacts that the events can have on Mammoth Cave's natural and cultural resources. While the current study provides much needed baseline data, more in-depth research is needed.

References

Trimboli, S.R., Toomey, R.S., Weber, K., and Ryan, S., 2011, The Misbehaving Spring: Studying Unique Underground River Flow Patterns with Advanced Middle School Science Students, in Proceedings, George Wright Society Conference on Parks, Protected Areas, and Cultural Sites, p. 311-316.

Clastic Sediments in Karst as a Vehicle for Contaminant Transport: Lithofacies and Transport Mechanisms

Rachel Bosch and William B. White¹

¹ Pennsylvania State University

Abstract

Karstic aquifers carry a load of clastic sediment as part of their hydrologic function. Clastic sediments are an important part of the mechanism for storage and transport of contaminants; indeed, solid contaminants can be considered as a form of clastic sediment. Although the sources of clastic sediments have been well delineated, sediments from multiple sources are mixed and redistributed within the aquifer to produce the sediment deposits observed in caves or the load of sediment discharged from karst springs. As an aid to the interpretation of clastic sediments in karst aquifers, a facies concept has been devised based on the traditional criteria of sedimentary petrology. Facies are defined in terms of particle size, degree of sorting, and sedimentary structures. The deposits represented by each set of facies characteristics in turn can be interpreted in terms of depositional mechanisms. The facies interpreted as slackwater cave deposits, here referred to as *slackwater facies*, are laminated deposits of clay to silt laid down in passages filled with stagnant water either flooded by inputs from upstream or backflooded from surface streams. This mechanism provides two pathways by which microorganisms or metals can be adsorbed onto clay particles and carried into the aquifer. The facies interpreted as channel cave deposits, here referred to as *channel facies*, consist of silts, sands, gravels, and cobbles carried in major conduits mostly by high velocity storm flows. Flows that transport sediments resulting in channel facies also can carry solid contaminants at various size scales and can act as storage sites for contaminants over long periods of time. Calculations show that hydraulic conditions required for transport leading to deposition of channel facies are consistent with observed discharge characteristics of major conduits.

Green River Alluvial Terraces at Mammoth Cave and Glacial Valley Trains on the Ohio River: Genetic Correlation Revisited

Joseph A. Ray

Introduction

The following analysis details how a correlation has not been successfully demonstrated between tributary back-ponding caused by glacial valley trains in the Ohio River Valley and two purported Wisconsin-aged alluvial terraces on the Green River at Mammoth Cave National Park (MCNP). This issue is important because the Ohio River impoundments continue to be reported as a genetic cause after nearly 30 years:

At present, the Green River valley at Mammoth Cave is filled with 10 m of sediment that accumulated behind Wisconsin valley trains in the Ohio River (Granger et al., 2001, p. 834).

In the subsection *Geomorphic History of the Ohio River Basin*, by F.-D. Miotke, in Miotke and Palmer (1972), the senior author compares terrace heights above each river:

The elevation of the Green River terraces roughly ten feet higher than those of the Ohio at Owensboro is in accordance with the normally higher gradients of other tributary rivers further up the Ohio valley (p. 26).

However, Miotke commits errors in his calculation of three landform heights above the Ohio River (Table 1a). For example, the Ohio River's upper terrace (Tazewell) is 64 ft above the river rather than the reported 44 ft ($341+64=405$). These faulty comparisons apparently led Miotke to the invalid "roughly ten feet higher" statement for the Green River, and thus an unjustified terrace correlation based on relative heights. Presumably, Ohio River alluvial landforms are greater than those of the Green River

Table 1a: Revised Ohio River data

Ohio River (near Owensboro)	Elevation (ft AMSL) (Ray, 1965)	Height above natural Ohio River (ft)
Natural low water	341	0
Floodplain	380	21-39
Cary terrace	390	39-49
Tazewell terrace	405	44-64

Table 1b: Revised Green River data

Green River (at Turnhole Bend)	Elevation (ft AMSL)	Height above natural Green River (ft)
Natural low water (approximate)	~410	0
Flood channel or First bottom	435-440	25-30
Second bottom (rare)	445-450	35-40
Third bottom (primary terrace)	455+	45+

because of the Ohio River basin's larger size and its direct glacial-outwash legacy. A review of this publication by Watson (1972) failed to notice the calculation errors concerning landform heights above the Ohio River.

Table 1b shows the author's most recent field observations (3/28/15) of Green River landform elevations at Turnhole Bend (shown in bold). These data are based on an approximate natural low-water datum of 410 ft for the Green River prior to impoundment by Lock and Dam #6 at Brownsville. The revised terrace heights above the Green River are 10-15 ft lower than Miotke's estimates.

Field Observations at Turnhole Bend

The first alluvial bottom above the Green River is nearly ubiquitous. This narrow floodplain is typically less than 100 ft wide and experiences frequent inundation. Also termed a flood channel, it has a rough surface because of localized deposits of mud, sand, and wood debris alternating with scour pits around tree roots. River-side slumping of alluvium is common with individual scars up to 100 ft in length. The second bottom is mostly missing along the upstream and downstream portions of Turnhole Bend, where a steep scarp rises 15-20 ft from the flood channel to the third bottom. It is often missing or indistinct elsewhere along the river. The third bottom and highest observed Green River alluvial terrace is extensive at Turnhole Bend, ranging from about 300-500 ft wide. It rises to an elevation of about 455+ ft, or 45+ ft above the natural low water level of ~410 ft. Miotke's upper alluvial terrace reported at 465-470 ft elevation is exaggerated at 55-60 ft above the revised datum of ~410 ft.

Both terraces at Turnhole Bend contain natural levees and back-swamp channels or

sloughs, creating relatively smooth terrace treads that slope gradually away from the river. These features show that the terraces at Turnhole Bend are active alluvial units currently inundated and partially shaped by major floods. The observed terrace elevation agrees with the 440 ft elevation contour (20 ft contour interval) paralleling mapped Quaternary alluvium (Qal) at Turnhole Bend and matches the description noted on the Rhoda Geologic Quadrangle map: *Along major rivers, clay and silt occur as high as 30 feet above normal water level* (Klemic, 1963) (adjusted to 40 ft above natural low water level of ~410).

In addition, two bedrock strath terraces exist above the main alluvial terrace at Turnhole Bend. The major strath is a dissected limestone bench consisting of rounded divides between sinkholes as much as 20 ft deep. At an elevation of 500-510 ft and up to 500 ft wide, the strath lies about 100 ft above the natural river level and is prominent at this and other meander bends along the river. Miotke and Palmer accurately show this landform in Figure 52, which is labeled Yarmouthian-Illinoian (?). However, a minor strath located between the major strath and the upper alluvial terrace is missing from this illustration. This narrow sinkhole-dissected landform, probably related to the previous interglacial stage, is not readily shown by topographic contours and can be difficult to view in the field because of woodland and cedar thickets. At an elevation of about 465-470 ft, this rocky strath is located at the same position as the Upper Wisconsin terrace illustrated in Figure 52 as a broad sandy alluvial terrace sloping toward the river. When compared with the revised terrace profile shown in Figure 1, it appears that Miotke and Palmer may have omitted the rare second bottom and mistook the 1st strath as the upper alluvial terrace. The

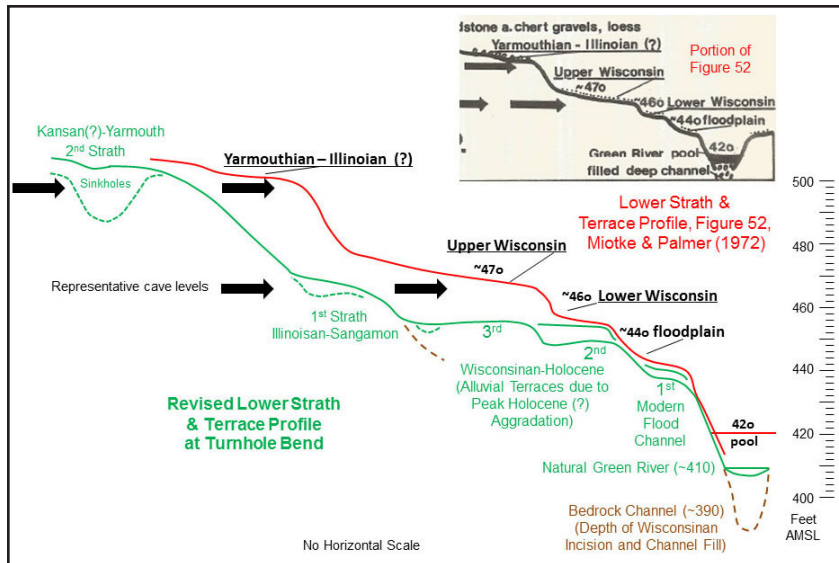


Figure 1: Comparison of bedrock strath and alluvial terrace profile at Turnhole Bend by Miotke (above, from Figure 52) and revised profile by Ray (below, from field observations on 3/28/15).

lowest representative cave level shown in Figure 52 aligns with the minor strath rather than an upper alluvial terrace, as shown.

Based on natural low-flow levels, the Green River elevation at Turnhole Bend is 69 ft (21 m) above that of the Ohio River near Owensboro, a basic relation reflecting the distance and significant gradient between the two sites. Using observed elevations, the two Green River terraces are about 50-60 ft (15-18 m) higher in elevation than the Tazewell and Cary-aged glacial outwash terraces of the Ohio River. Green River terraces are not likely to have accumulated “behind Wisconsinan valley trains in the Ohio River” when at Mammoth Cave those terraces are considerably higher in elevation and 135 valley miles (218 km) distant from the back-ponding Ohio River. Interestingly, the Ohio River floodplain alluvium of known post-Cary (Holocene) age stands up to 39 ft above the low river elevation of 341 ft, which is similar to the total height of the Green River bottomlands of 45+ ft above the natural low water level of ~410 ft. This similarity

in height above natural river levels would be reasonable if the Green River terraces were also Holocene in age, whereas the Ohio River outwash terraces are comparatively greater.

Discussion

Weller (1927, p. 77) considered the maximum level of glacial “Green Lake” to be about 420-440 ft, and that the easternmost extension of late Wisconsin ponding occurred near the mouth of Honey Creek, more than 18 miles down-valley of Turnhole Bend. Stein (1980) and Morey et al., (2002) show the upstream extent of lake silts ending near Big Reedy Creek, about 29 miles down-valley of Turnhole Bend. Stein’s longitudinal profile of the Green River also shows a flat lake plain below Paradise, KY, more than 70 miles down-valley of Turnhole Bend (Figure 2). This lake plain, lying at about 385-390 ft elevation, undoubtedly developed in lake waters impounded behind the Tazewell and Cary valley-train terraces at 410 and 390 ft, respectively. The lake

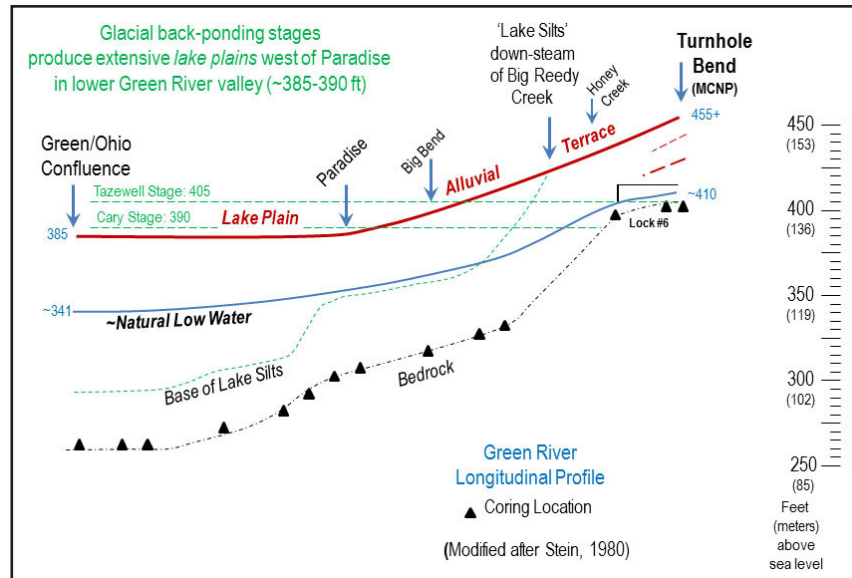


Figure 2: Green River longitudinal profile showing main alluvial terrace merging with lake plain formed by back-ponding during Tazewell and Cary glacial outwash stages on the Ohio River. The main alluvial terrace at Turnhole Bend lies 65-70 ft higher than the lake plain.

plain extends about 62 miles up the lower Green River valley, which is just over the 44 mile reach of Wisconsin ponding on the Kentucky River (Andrews, 2004, p. 97).

Geochronology based on ^{14}C dating is unavailable for the Mammoth Cave terraces, but, since Miotke's correlation with Ohio River terraces was based on inaccurate data and interpretations, a Holocene age for the upper portion of the Green River alluvial fill remains a viable hypothesis. Herrera (2007) investigated alluvial terraces 0.5-40 km up-valley of MCNP, and identified two primary alluvial landforms. The main bottomland terrace was described as Early Holocene alluvium, at >143 m (470 ft) elevation, and narrow stream-bordering floodplains were labeled as Lower Holocene alluvium. He obtained several ^{14}C dates from low floodplain sediments. Organics sampled from three boreholes 3.2-3.5 m deep returned modern dates ($120-180 \pm 40$ yr BP), and two island bank exposures were determined to be younger. A single older

date of 2320 ± 40 yr BP was obtained from an island deposit 5 m deep suggesting a remnant of late Holocene deposits buried by the modern floodplain (Herrera, 2007, p. 88).

Herrera's modern floodplain dates agree with Knox (2006), who determined that historical floodplain deposits, commonly inset against a previous floodplain, in Wisconsin and across the American Midwest are largely the result of abrupt river-regime responses to widespread deforestation and cultivation practices over the last 175-200 years. These modern dates conflict with Miotke, who interpreted this low flood-channel unit as the sole Holocene-aged landform (2nd table, p. 52). Elsewhere, early to mid-Holocene alluvial fills have been dated in Nebraska (Brice, 1966), Iowa (Ruhe, 1969), Wisconsin, Illinois, and Indiana (Gooding, 1971), and Tennessee (Brakenridge, 1984).

Verified by recent field observations, straths and alluvial bottoms at Turnhole Bend are mapped in Figure 3 on a recently available

LiDAR KY-DEM 5ft hillshade basemap (KYAPED, 2015). Strath ages (A & B) are estimated based on glacial/interglacial cycles (Paillard, 2001; Martin, 2007), with the most recent cycle (C) subdivided into three alluvial bottomlands attributed to Holocene (?) through Modern times.

Key Findings

This reassessment does not differ with the demonstrated linkages between cave levels and regional Green River strath development. A correlation with glacial back-ponding appears to be accurate for the lower Green River valley, west of Paradise, where over 160 mi² of flat alluvial/lacustrine plains, or lake plains, lie at about 385-390 ft elevation. However, a genetic correlation of alluvial terraces in MCNP with Ohio River glacial terraces cannot be substantiated by Miotke's work. Significant findings of this research include:

- Relative to heights above each river, Ohio River landforms are 9-19 ft (3-6 m) higher than those of the Green River.
- Green River alluvial terraces are 50-60 ft (15-18 m) higher in elevation than, and 135 valley miles (218 km) upstream from, glacial terraces of the Ohio River, making a correlation based on back-ponding very unlikely.
- The Green River's second bottom is usually missing or indistinct, whereas the third bottom or main alluvial terrace is conspicuous along the river.
- A minor bedrock strath can be identified just above the main alluvial terrace at Turnhole Bend and other sites. This key landform was not described by Miotke.

This Wisconsin/Holocene hypothesis applies to the genesis and sequence of terrace

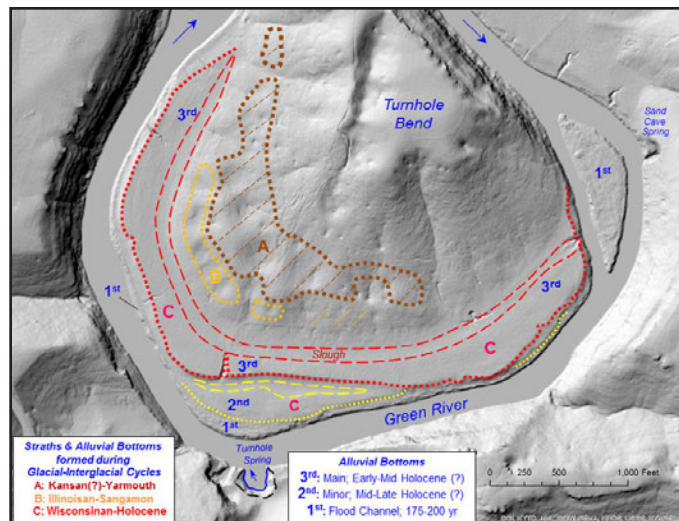


Figure 3: Shaded-relief LiDAR image showing estimated boundaries of two bedrock straths and three alluvial bottoms of the Green River at Turnhole Bend, including proposed ages.

construction in absence of a demonstrated back-ponding control as far upriver as the Mammoth Cave Plateau. This hypothesis is supported by a) corrected elevation data for the Ohio and Green rivers and revised landform comparisons, b) a published Green River profile showing MCNP considerably upstream and higher in elevation than identified lake plains and silt deposits in the lower valley, and c) modern post-settlement dates for the Green River flood channel. Pleistocene dynamics in unglaciated rivers can probably best be characterized as sequential glacial-interglacial cycles producing vertical river oscillations within overall valley incision. At Turnhole Bend, a major Green River channel incision during the low-sea Wisconsin Stage was reversed by Tazewell/Cary-aged channel filling and ensuing Holocene floodplain construction, vertically totaling as much as 65 ft (20 m). Within the gorge, the river and bottomlands currently develop a fairly consistent overall width of about 650 ft (200 m).

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References cited

- Andrews Jr., W.M., 2004, Geologic controls on Plio-Pleistocene drainage evolution of the Kentucky River in central Kentucky: PhD dissertation, University of Kentucky, 216 p.
- Brakenridge, G.R., 1984, Alluvial stratigraphy and radiocarbon dating along the Duck River, Tennessee; implications regarding flood-plain origin: Geological Society of America Bulletin, 95 (1): 9-25.
- Brice, J.C., 1966, Erosion and deposition in the loess-mantled Great Plains, Medicine Creek drainage basin, Nebraska, U.S. Geological Survey, Prof. Paper 352-H, p. 255-339.
- Gooding, A.M., 1971, Postglacial alluvial history in the upper Whitewater basin, southeastern Indiana, and possible regional relationships: Am. Jour. of Science, 271: 389-401.
- Granger, D.E., Fabel, D., and Palmer, A.N., 2001, Pliocene-Pleistocene incision of the Green River, Kentucky, determined from radioactive decay of cosmogenic (super 26) Al and (super 10) Be in Mammoth Cave sediments: Geological Society of America Bulletin, 113 (7): 825-836.
- Herrera, Juan, 2007, Quaternary Alluvial Deposition in the Upper Green River Valley, Kentucky: Western Kentucky University, Masters Theses & Specialist Projects, Paper 422, 113 p.
- Klemic, Harry, 1963, Geology of the Rhoda Quadrangle, Kentucky: U.S. Geological Survey GQ-219, Washington, D.C.
- Knox, J.C., 2006, Floodplain sedimentation in the Upper Mississippi Valley: Natural versus human accelerated: Geomorphology, 79 (3-4): 286-310.
- KYAPED, 2015, Kentucky Digital Elevation Model – 5ft Hillshade, KYAPED Partners. Metadata available at: <http://kygisserver.ky.gov/geoportal/catalog/search/resource/details.page?uuid=%7BB8D151AA-6C15-4F68-95ED-65F341CA9E2E%7D>
- Martin, J.M., 2007, Quantitative sequence stratigraphy: PhD dissertation, geology, University of Minnesota, 193 p.
- Meotke, F.-D., and Palmer, A.N., 1972, Genetic relationship between caves and landforms in the Mammoth Cave National Park area, A preliminary report, Druck: Bohler, Wurzburg, West Germany, 69 p.
- Morey, D.F., Crothers, G.M., Stein, J.K., Fenton, J.P, and Herrmann, N.P., 2002, The fluvial and geomorphic context of Indian Knoll, an Archaic Shell Midden in West-Central Kentucky: Journal of Geoarcheology, 17 (6): 521-553.
- Paillard, Didier, 2001, Glacial cycles: toward a new paradigm: Reviews of Geophysics 39 (3): 325-346.
- Ray, L.L., 1965, Geomorphology and Quaternary geology of the Owensboro Quadrangle, Indiana and Kentucky: U.S. Geological Survey, Professional Paper 488, 72 p.
- Ruhe, R.V., 1969, Quaternary Landscapes in Iowa: Ames, Iowa State University Press, 255 p.

Stein, J.K., 1980, Geoarcheology of the Green River shell mounds, Kentucky: unpublished PhD dissertation, University of Minnesota, Minneapolis.

Watson, R.A., 1972, Review: Genetic relationship between caves and landforms in the Mammoth Cave National Park area, A preliminary report, by Franz-Dieter Miotke & Arthur N. Palmer: *Caves and Karst* 14 (6): 44-46.

Weller, J.M., 1927, The Geology of Edmonson County: Kentucky Geological Survey, Ser. 6, vol. 28, 246 p.

Spatial Distribution Map of Small Caves within Mammoth Cave National Park

Bill Copeland¹

¹ Cave Research Foundation

Abstract

This map is the product of five years of work by John Kirk, the Cave Research Foundation, employees of Mammoth Cave National Park, and myself. This map was constructed using ArcMap 10.3 using a plain background to mask the locations of the caves in the park. Two things stand out. First, there have been more caves located on the south side of Green River, and second, more caves have been surveyed on the north side of the river. During the late 1980s into the 90s, there was a concentrated effort to find and survey small caves on the north side, especially ones that hosted a significant number of bats. What the map doesn't show, but would have if locations were placed on a geologic map, is that north side caves tend to be found along the creeks within the Haney Limestone, and the south side caves tend to be located at or near the Big Clifty/Girkin contact, with a small number found at the bottom of the deep karst valleys.

Effects of Faulting on Past and Present Hydrogeology in Long Cave, Mammoth Cave National Park

Rickard A. Olson¹ and Rickard S. Toomey²

¹ Division of Science and Resources Management, Mammoth Cave National Park

² Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park

Introduction

Long Cave is located near the southeastern corner of Mammoth Cave National Park, and the Cave Research Foundation survey stands at 1.32 miles or 2.13 kilometers (Osburn 2003). Though Long Cave is not very long by local standards, almost all of it is large trunk passage corresponding to Palmer's Level B in Mammoth Cave (Palmer 1981). There are many fascinating aspects to Long Cave, such as the activities of prehistoric Indian cavers, large colonies of bats, saltpeter mining during the War of 1812, cave tours in the 19th century, a hermit (Sides and Warnell 2013), and of course geology.

In general, geologic structure in the area is subtle, with strata dipping to the northwest roughly at less than a degree (Palmer 1981) although the Turnhole Bend area of the park displays considerable faulting (Olson and Toomey 2009). Long Cave is unusual in that seven faults are visible in less than a mile and a half of passages.

These faults probably date to the Cretaceous Period about 100 million years ago, and appear to have had effects on cave development in the range of 3-10 million years ago under phreatic conditions. In some cases there are apparent effects today under vadose conditions. The faults described in this paper have not been previously reported, and were discovered during paleontological inventory work conducted in 2001.

Field Measurements

Strike and dip data were taken with Suunto compass and clinometers respectively. Displacements were measured with a fiberglass survey tape graduated in feet and tenths of feet where possible. The faults are described in the following paragraphs,

with locations shown in Figure 1, and data summarized in Table 1.

The first significant fault encountered in the cave is at the junction of the entrance passage and Grand Avenue, near survey station A19, there is a normal fault with a strike of 45 degrees, a dip of 47 degrees to the northwest, and a displacement of 46 centimeters (18 in) down to the southeast. There is also a fracture running down the axis of the entrance passage near station Z8 with an orientation of 46 degrees but with no visible displacement or dip. However, there is a breccia zone up to 15cm (6in) wide (Figures 1 and 2).

At the junction of the main passage and the Echo Passage, a fault is visible in the north wall near survey station X1 (Figure 3). This is a reverse fault with a strike of 62 degrees, a dip of 83 degrees to the northwest, and a displacement of 1.37 meters (54 inches) down to the southeast. The fractures exposed in the wall at X1 are very complex so this description may not be complete. What seems likely to be the same fault or closely related is visible in the

walls of a shaft complex at survey station DA5. It is too high up the wall to measure the displacement directly, but is estimated to be about 1.2 meters (48 inches) down to the southeast. It has a strike of 54 degrees and appears to be vertical. Being so close to one another, it is difficult to imagine that the faults at X1 and DA5 are not closely related despite the differences in strike and dip. This part of the cave needs closer study.

Further south in the Echo Passage, a fault crosses near survey station D19. This vertical fault has a strike of 49 degrees, and a displacement of approximately 30 cm (12 inches), down to the southeast.

Near the end of the Echo Passage there are two more small faults. One is located near survey station X33, and is vertical with a strike of 48 degrees and a displacement of 15 cm (6 inches), down to the southeast. The other fault is near survey station D2B, is also vertical, and has a displacement of 30 cm (12 inches), but is down to the northwest, opposite of all the others.

Finally, in Grand Avenue about 60 meters (200 feet) west of the Echo Passage/Grand Avenue junction, there is a fault at survey station Y6. This is a vertical fault with a strike at 75 degrees and a displacement of 50 centimeters (20 inches), down to the southeast.

Table 1: This tabulation summarizes location, orientation, displacement, and other characteristics of faults observed in Long Cave.

Nearby Station	Fault Type	Displacement	Strike	Dip
A19	Normal	46cm / 1 8in	45°	47°
X1	Reverse	1.37m / 54in	62°	83°
DA5	Normal	~1.2m / 48in	54°	90°
D19	Normal	30cm / 12in	49°	90°
X33	Normal	15cm / 6in	48°	90°
D2B	Normal	30cm / 12in	38°	90°
Y6	Normal	50cm / 20in	75°	90°

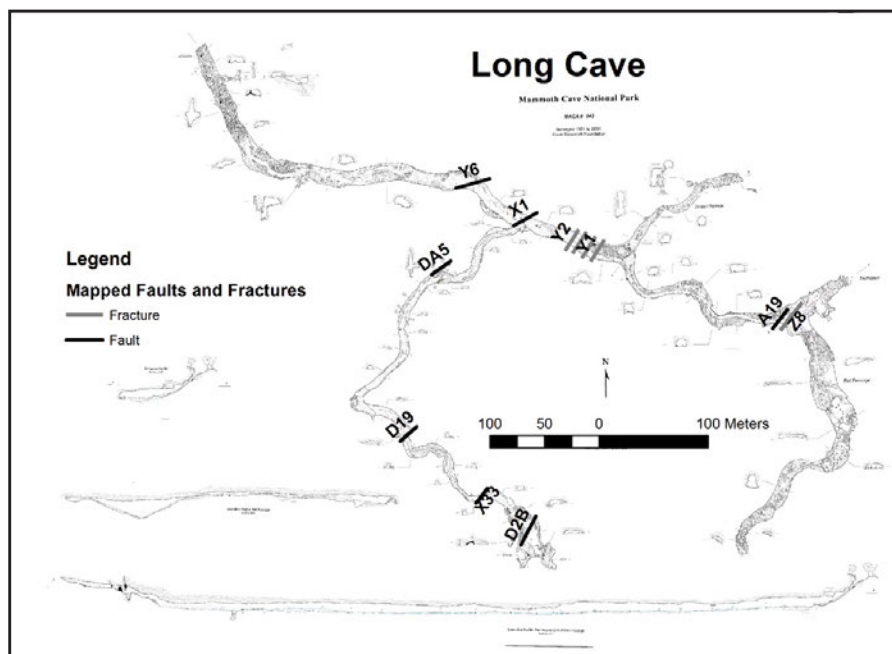


Figure 1: Map of Long Cave showing locations of faults and fractures discussed in the text. Base map courtesy of Bob Osburn and the Cave Research Foundation; map modified by Rick Toomey.

Effects of the Faults and Fractures

Passages in the Mammoth Cave area are not generally fault or fracture controlled, so it would be unusual if the entrance passage development was affected by the fault at A19 or the fracture with breccia running down the entrance passage ceiling at Z8 (see Figure 1). However, we can make a couple of observations that raise interesting questions.

First, if the entrance passage was tributary to the main flow coming from the south, then there would be two large passages contributing to westward flow in Grand Avenue, but this passage is smaller in cross-section. Second, there is a phreatic ceiling channel along the axis of the fracture seen at Z8, which could indicate flow to the

northeast. The beginning of this phreatic ceiling channel and the fracture can be seen in Figure 2, and more of it is visible in an unpublished LIDAR scan conducted by Aaron Addison of the Cave Research Foundation. This part of the cave needs closer examination.

At survey station X1, the fault resulted in a high phreatic ceiling fissure across Grand Avenue to the junction with the Echo Passage, which was a tributary to Grand Avenue. The displacement of this fault is more than most in the Mammoth Cave area, and it appears to have caused an unusual orientation between this tributary and Grand Avenue.

Normally a tributary passage joins a main passage at an angle of 90 degrees (perpendicular) or less such that the

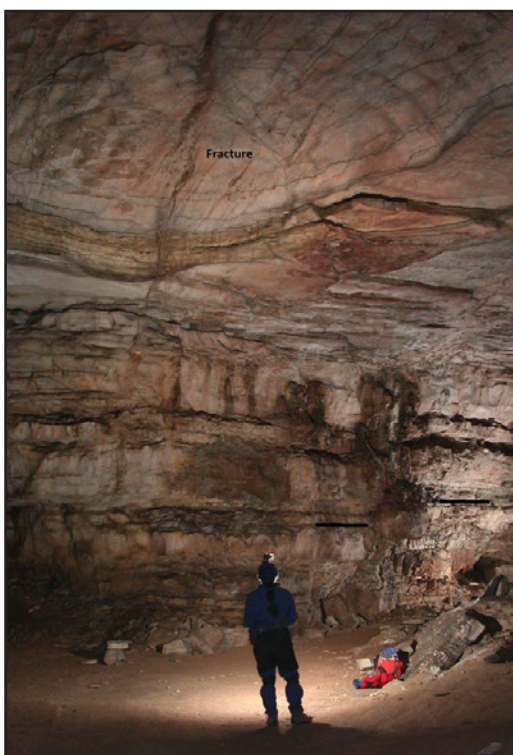


Figure 2: Fault at A19 and fracture at Z8 where the entrance passage joins Grand Avenue. The fault is shown with black bars to the right of Mona Colburn, and the brecciated ceiling fracture is labelled at top center. All photos are by Rick Olson unless otherwise noted.



Figure 3: Fault in Grand Avenue at X1. Displacement is shown with black bars on either side of Mona Colburn.

waters flow together in a normal dendritic pattern. In this case however, water from Echo Passage was flowing eastward in the direction of about 80 degrees and had to turn 140 degrees to join the main flow in Grand Avenue. At this passage junction, it appears that water would have flowed to the southeast, but scallops in Grand Avenue indicate flow to the west and north.

The shaft complex at DA5 is developed within the same fault seen at X1, or in one closely related. Apparently this fault allowed water to penetrate the sandstone/shale cap rock in a part of the cave that is otherwise very dry (Figure 4).

On either side of the fault at D19, passage morphology is quite different. To the southeast (paleo-upstream) it is a walking-height canyon. Northwest of the fault, the passage abruptly becomes a low wide tube of stoop-walking height. As well, the passage changes from moist in the southeast portion to dusty dry in the northwest. This is because an intermittent stream flowing from the southeast sinks under the northwest wall of the passage where the fault is located (Figure 5).

The fault at X33 facilitated development of a high phreatic ceiling fissure approximately 6 meters (20 feet) high with much breccia visible. The nearby fault at D2B also resulted in upward solution along the fracture. At both of these faults a purple patina is prominent on the ceiling, and at D2B there is flowstone tinted green. The cause of this coloration is not known, but investigation by a microbiologist is recommended (Figure 6). These two faults and the one at D19 are all oriented toward Grand Avenue between the entrance passage and the beginning of Echo Passage, but the only expression of tectonic action in this area is a fracture swarm with a strike of 31 degrees located near survey

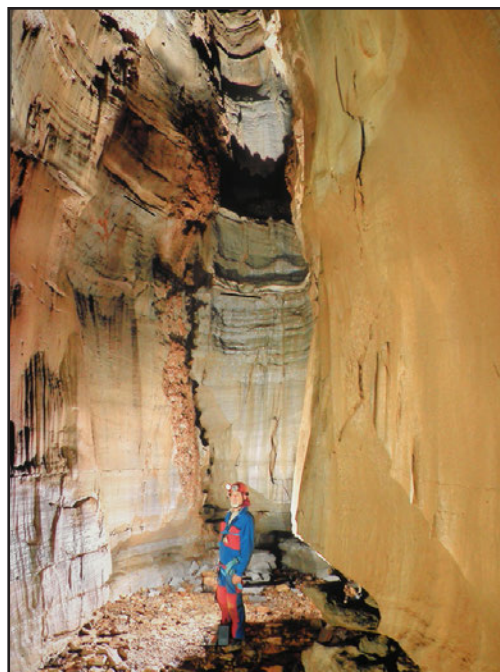


Figure 4: Fault in shaft off the Echo Passage near DA5. Displacement is shown with black lines high above and left of the caver. Rough looking material exposed in the wall to the left of the caver is breccia. Photo by Gary Berdeaux.



Figure 5: Echo Passage at D19 showing the change in passage cross-section from walking canyon to the southeast and stoop way to the northwest (direction of view) on either side of the fault. The hole in sediment to the right of Mona Colburn is where water from an intermittent stream sinks.

stations Y1-2. (Figure 7). Passage orientation and general morphology appear to have been unaffected by this fracture swarm.

At the fault near survey station Y6, Grand Avenue turns from trending 330 degrees to 270 degrees at the fault. However, there is no way to know if the fault caused this bend.

Regional Setting

All of the faults and fractures noted are oriented generally northeast/southwest, and are possibly related to the Pennyrile Fault System, which is part of the southern boundary of the Rough Creek Graben (Figure 8), an arm of the Illinois Basin. The park is within the eastern end of the graben, which extends west as far as Southern Illinois. Locally, structural effects of the graben are comparatively subtle, but to the west in the deepest part of this depression, basement rocks are as much as 7 kilometers or a little more than 4 miles below the surface (Kolkata and Nelson 1997). Generally, faults on the margins of the graben have displacement stepping into the graben, but only one of the observed faults in Long Cave does that. As well, the largest fault in this set (at X1) is a reverse fault that would be formed under compression rather than the tension creating the graben. So the faults in Long Cave may be related to a different geological event.

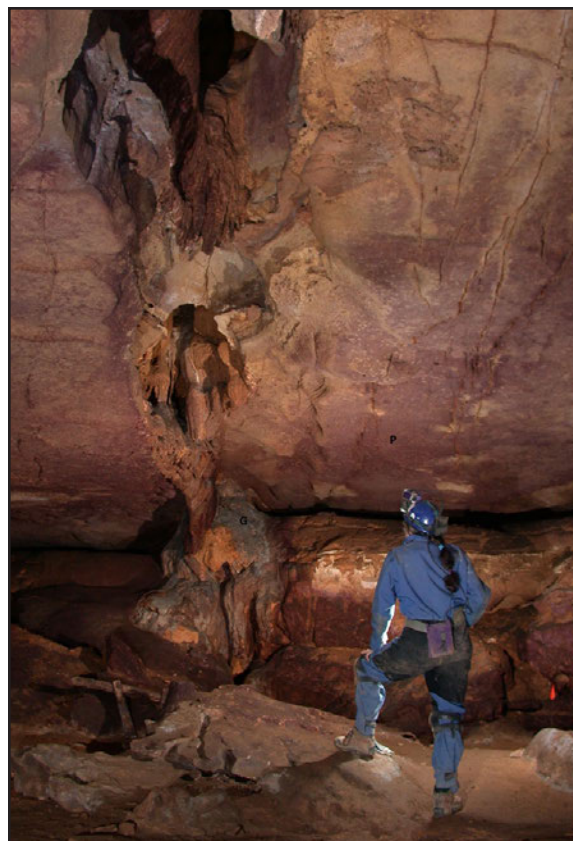


Figure 6: Fault at D2B showing the ceiling channel plus green tinted flowstone (G) and purple wall coatings (P).



Figure 7: Fracture swarm in Grand Avenue at Y1-Y2. This impressive fracture set apparently had no influence on passage development.

Conclusion

Long Cave has an unusual concentration of faults for the region. The fault at A19 and especially the fracture at Z8 may have influenced development of the entrance passage. The fault at DA5 appears to have controlled shaft development adjacent to Echo Passage, and a likely related one at X1 appears to have affected the entry angle of Echo Passage with Grand Avenue. Another fault at D19 in Echo Passage may have caused a change in cross sectional shape, and affects modern hydrology of the passage. Unusual purple coloration on passage walls at X33 and D2B plus green flowstone at the latter station may indicate unusual microbial activity. As usual, more research is needed.

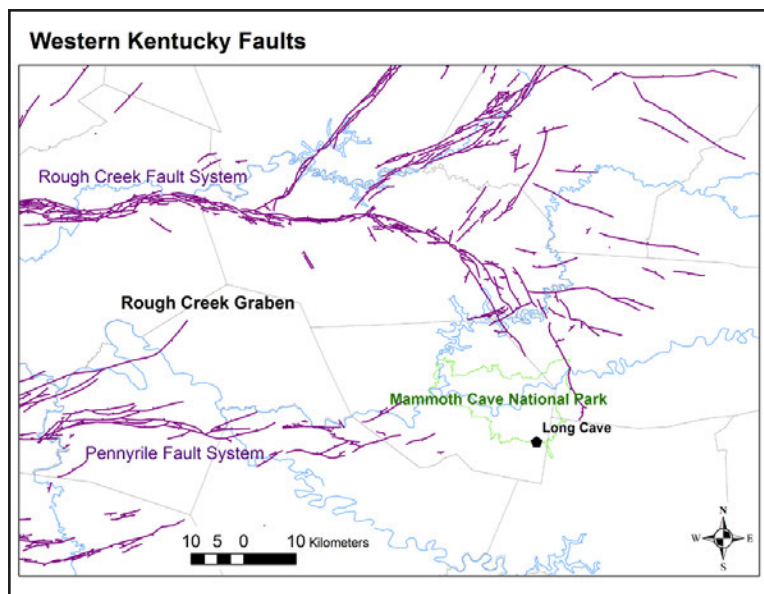


Figure 8: Map showing the location of Long Cave and Mammoth Cave National Park within the Rough Creek Graben. Base map by Kentucky Geological Survey; map modified by Rick Toomey.

Literature Cited

- Kolkata, D. R. and W. J. Nelson. 1997. Role of the Reelfoot Rift/Rough Creek Graben in the evolution of the Illinois Basin. In Ojakangas, R. W., Dickas, A.B., and J. C. Green, eds. Middle Proterozoic to Cambrian Rifting, Central North America: Boulder, Colorado, Geological Society of America Special Paper 312, p. 287-298.
- Palmer, A. N. 1981. A geological guide to Mammoth Cave National Park. Zephyrus Press, Teaneck. NJ, p. 69, 135.
- Olson, R. and R. Toomey. 2009. A Major Unmapped Fault In Ganter Cave, And Possible Geomorphological Effects On Turnhole Bend Of Green River, Mammoth Cave National Park. Proceedings 15th International Congress of Speleology. Edited by W. White, V. 3, Kerrville, TX. P. 1626-1631.
- Osburn 2003. Map of Long Cave. Cave Research Foundation, Hamilton Valley Road, Cave City, KY 42127
- Sides, S. and N. Warnell. 2013. Long Cave, Mammoth Cave National Park, Edmonson County, Kentucky. Mammoth Cave National Park's 10th Research Symposium: Celebrating the Diversity of Research in the Mammoth Cave Region, February 14-15, 2013, p. 139-142.

Natural Resource Condition Assessment for Mammoth Cave National Park

Cate Webb¹, Chris Groves², and Katie Algeo³

¹ Ogden College of Science and Engineering, Western Kentucky University

² Crawford Hydrology Laboratory, Western Kentucky University

³ Department of Geography and Geology, Western Kentucky University

Abstract

The 1916 Organic Act established the National Park Service (NPS) with a purpose to conserve the scenery, natural and historic objects, and wildlife within national parks by such means as will leave them “unimpaired for the enjoyment of future generations.” This requires a metric by which the conditions of relevant resources can be evaluated. For NPS this is done through the Inventory and Monitoring (I&M) Program Network and by individual park Science Divisions along with cooperating partners. Natural Resource Condition Assessments (NRCAs) for national parks report on current conditions, critical data gaps, and condition influences for selected resources in the parks to assist land managers with protection, restoring and maintaining resources. An NCRA is underway for Mammoth Cave National Park (MACA). Selection of the resources evaluated in this assessment is based on the NPS Ecological Monitoring Framework. This has four hierarchical levels to structure the resources being considered, and is based on resource conditions at MACA. The Level 1 categories include Air and Climate, Geology and Soils, Water, Biological Integrity, Human Use, and Landscapes (Ecosystem Patterns and Processes). The lower level subdivisions reflect both expected finer details as well as the varieties of surface and underground resources. The principal resource threats at MACA are based on external influences including impacts to water quality and air quality, as well as from invasive species. White Nose Syndrome, a fungal and often fatal disease afflicting bats that was first identified in 2006 was confirmed at MACA in 2013, and Kentucky’s forests are threatened by several diseases and insects. An interesting and bright spot concerns air quality, which has long been deteriorated by regional pollution sources. Following coal power plant emission improvements in the late 2000s, annual average rainfall pH has risen from below 4.7 to over 5.1, while SO₄ concentrations have fallen by 45%.

Meta-Analysis of Research Conducted at Mammoth Cave National Park, 1980-2013

Andrea Bachman¹, Nicole Erb¹, Ellen McPhillips¹, Matthew Rice¹, Tawni Riker¹, and David Kime¹

¹ Honors Program, Northern Kentucky University

Abstract

National Parks serve as excellent public partners for pursuing multiple fields of research. Park employees and outside researchers conduct research related to park history and resources. Kentucky's own Mammoth Cave National Park is the site of particularly broad areas of research, including anything from the area's 350 million years of geologic and biologic history and 4000 years of human history both above and below ground. Our project surveys research related to Mammoth Cave National Park from 1980 to 2013, including discipline, method, cave versus surface, and demographics of the researchers, and reviews trends and changes in this research.

Ongoing Geographic Documentation of the Mammoth Cave System and Related Caves

Pat Kambesis¹ and Bob Osburn¹

¹ Cave Research Foundation

Abstract

One of the challenges of studying and protecting the globally significant resources of Kentucky's Mammoth Cave National Park is that many of them are underground. The Mammoth Cave System, with a current known length of over 675 kilometers and still growing, is the most extensive known cave on Earth. The primary reason the survey of the cave system is not yet complete is because of the cave's enormity. The Cave Research Foundation (CRF) Cartography Program has been collecting detailed geographic data from the caves of Mammoth Cave National Park, to produce cartographic interpretations of the data in the form of various types of maps, and to incorporate that data into a master data archive system. Copies of data and maps are provided to the Division of Science and Resource Management (SRM) at Mammoth Cave National Park via the conditions of an official Cartographic Research Project. In cooperation with SRM, the Cartography Program conducts ten expeditions a year in the park in a continuing effort to explore, survey, inventory and document the caves. Not only does this work identify locations and geometry of the passages themselves, but also documents the biological, mineralogical, cultural, archeological, and paleontological resources they contain. The maps produced by the CRF Cartography Program are an important resource for management of the cave and for scientists who study the cave, its water, and how the cave relates to the associated landscape. It is now known, for example, in large part by cave survey that the upstream ends of several of the cave's most significant underground rivers extend far beyond the park boundaries to agricultural land, industrial sites, and transportation corridors that pose detrimental impacts to the cave's water quality and aquatic ecology. The maps also provide critical resources for scientists in several other ways – base maps to plot the features they study, as well as “roadmaps” to find their way around (and back out of) this enormously complex labyrinth. A currently evolving task involves integration of these surveys into Geographic Information Systems databases and maps. CRF is also surveying and documenting other significant caves in the park, including Lee Cave (12+ km), Wilson Cave (6+ km), and Smith Valley Cave (4+ km), as well as a large number of minor ones in the “Small Cave Inventory” project. The ongoing survey and cartography work provides the baseline information that is critical for understanding and protecting the karst resources within Mammoth Cave National Park.

Exploration of Mammoth Cave Pools with Submersible Remotely Operated Vehicles

S. Altenstadter¹, O. Hennis¹, C. Johnson¹, A. Willett¹, S. Hammer¹, and E. Wong¹

¹ Mercy Academy

Abstract

Mammoth Cave contains a number of partially explored bodies of water. While some of the hydrology is known, and some unique aquatic species have been discovered and described in these environments, the difficulty of accessibility has discouraged more thorough investigation. This project has two aims. The first aim is to provide a unique educational opportunity for high school students to take the ecological knowledge and engineering skills they have learned and used in the classroom and apply them to original research in the cave. The second aim is to expand the existing knowledge about the aquatic community ecology and geology of the cave system by using a remotely operated submersible to increase accessibility.

Students at Mercy Academy in Louisville, KY built and learned to operate a fully submersible, tethered, remotely operated vehicle (ROV) based on open source plans (OpenROV, www.openrov.com). After initial testing of the design in small enclosed aquatic environments, practical operation of the vehicle and its video capture capabilities was tested in Mammoth Cave's underground pools and rivers.

The ROV is equipped with on-board high-definition video recording capability, as well as a sensor suite that can monitor heading, depth, and temperature. Students learned to troubleshoot assembly and design issues, and, based on their in-cave experiences, have also begun to consider designing and producing modifications to the ROV at school using 3D-printing and laser cutting manufacturing techniques.

Survey of pools and other aquatic sites consist of two phases. The initial phase consists of free-piloting exploration of potentially interesting research sites. Then having decided upon areas for more intensive study, the ROV can be used to

perform more exhaustive and systematic surveys of specified areas of the pools at specified depths, allowing a comparison of populations in different parts of the pool (e.g. source vs exit, or shore vs center) and of populations in the same area of the pool, but at different depths.

We have performed initial explorations of parts of the River Styx (adjacent to Charon's Cascade) and the Dead Sea, doing some troubleshooting along the way, primarily with respect to managing the tether in an environment filled with potential snag points and in minimizing the disturbance of sediment, which can make video data collection difficult.

We have also begun the process of more systematically mapping the River Styx area, gathering bottom depth and video data at approximately ten points in the pool mapped by triangulation. This allows us to begin creating a 3D map of the pool. We are also examining the video for the presence of stygobites such as cave fish and cave crayfish.

From this point, continuation of the project is directed at completing a 3D underwater map of this part of the River Styx, describing the ecological characteristics of this section, and finally, to continue improving the ROV through design and engineering of enhanced sensors, chassis designs, and tools.

Redevelopment of Historic Tour Cave Trails

Rickard S. Toomey¹, III and Steve Kovar²

¹ Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park

² Mammoth Cave National Park.

Introduction

The renovation of the cave trails of the Historic Tour Route (HTR) is the largest cave project at Mammoth Cave National Park (MACA) since the CCC construction of the cave trails in the 1930s. It is the culmination of over 20 years of project development. When completed in May of 2017, this project will provide cave trails that should not need to be replaced for at least 50 years. The construction budget for the trails renovation is over \$5.8 million. When preparatory development projects, NPS staff evaluation and development time, archaeological and paleontological testing, cave trail surveys, and architectural and engineering design needed to support the project are included, the final cost of the project will be over \$10 million. For the entire construction project, the contractor estimates they will move between 2.5 and 3 million pounds of materials (pavers, concrete, aggregate, sand, steel, composite lumber, etc.) into the cave. This quantity includes approximately 9700 pavers and 190 tons of aggregate.

Project Goals

The goals of the renovation of the HTR trails are as follows:

- 1) Improve visitor experience and safety by providing better and more predictable trail surfaces
- 2) Improve protection of cave resources by keeping visitors on-trail, reducing dust and lint from cave trails, and ending the need to use dirt excavated in the cave to repair cave trails
- 3) Improve maintainability of cave trails and reduce long-term trail maintenance costs.

Issues Addressed by Project

These goals were developed as a response to park needs that had been identified as the trails aged and tour visitation increased. Problems associated with the existing trail surfaces were identified over the past 25 years.

These problems included:

- 1) Slick, steep trail sections where visitors could slip
- 2) Potholes which developed in dirt trails surfaces
- 3) Uneven, bumpy trails surfaces that developed in damp areas
- 4) Visitors easily stepping off the trail because trail edges were sometimes poorly delineated
- 5) Damage to cultural resources when people left tour trail
- 6) Extensive dust coating surfaces and artifacts along upper section of the HTR because dirt trail surfaces to turn in dust in dry conditions and tour passage drives the dust into the air to settle far from the trail
- 7) Barrow pits in sediment banks near the trail as dirt from the cave was used to fill potholes in the trail

Background and Scope of Project

The renovation of the HTR trails consists of upgrading the trail tread and edging (such as lint curbs and handrails). The trail alignment is remaining the same as prior to the renovation. Except for a few small wet and slippery areas where the tread will consist of fiberglass grating (such as what is used on the Mammoth Dome Tower), the project team chose pavers and concrete as trail surfaces. Larger, wider passages (such as Upper Historic and Great Relief Hall) will have concrete pavers as a trail surface. Smaller, narrower passages (such as Blacksnake, Sparks, and Little Bat Avenues) will have concrete trails surfaces.

Stairs and handrails are being added in places where trail slopes are particularly steep. Lint curbs are being added to areas with known lint and dust problems such as upper Historic and Spark's Avenue.

The HTR cave trails renovation project started with several demonstration projects in the late 1990s and early 2000s. These included several areas where the trail surface was replaced with pavers and the installation of a wood and composite lumber boardwalk in Broadway. These projects were designed and installed by park staff. Although they were constructed to help address trail issues, their primary purpose was to test two different trail surface approaches that the park would potentially use for a larger trail renovation.

As a result of these demonstration projects, the park staff determined that pavers provided a very good option for building a sustainable cave trail. Although the boardwalk solution is also considered viable for some trail segments, many people feel that it has several drawbacks (such as noise and visual intrusiveness) that rendered it a less desirable. In addition, the State Historic

Preservation staff noted that the boardwalk was not compatible with the cultural landscape of the Historic section.

In 2008 DDS Engineering performed an engineering survey of the cave trails to document their condition at that time (trail surface, slopes, etc.). This engineering survey provides the baseline map/CAD drawings for planning the HTR cave trail renovation.

In preparation for renovations of the park's cave tour trails, the park had the University of Kentucky Program for Archaeological Research (UK-PAR) conduct archaeological and paleontological investigation along selected trail segments in Mammoth and Great Onyx Caves. These investigations included the HTR.

As part of these investigations UK-PAR developed a map rating areas of the HTR as high, medium, or low archaeological and paleontological potential. These designations provided guidance for developing trail construction restrictions to best protect sensitive areas. For example, the area near Giant's Coffin was found to be highly sensitive from an archaeological standpoint. Because of this, the park had UK-PAR perform additional studies in that area to document archaeology that would be covered by the trail. In addition, the park designated that area as a no ground penetration area. This means that infrastructure for supporting the paver trail and lint curbs must be constructed on top of the existing trail surface.

The UK-PAR investigations also recommended having an archaeologist monitor digging activity associated with the construction. This recommendation was implemented during construction, with UK-PAR supplying an archaeologist to monitor activities in the cave.

Project Design

Trail design was developed in 2013-14 by the engineering firm VHB Inc. (Williamsburg, VA). The design process was iterative with the engineers and architects visiting the park, meeting with the NPS national and park review team, taking notes and pictures documenting conditions and potential issues on the trail, developing draft plans, and then repeating the process based on comments from the review team. The NPS review team included park staff representing all divisions, staff from the Denver Service Center, and NPS Southeast Region and Kentucky Historic Preservation staff.

During this process the team made many decisions about the trails. For example, the team chose to try to develop the trails with an organic layout that was similar to the existing trails. For a trail surface the team chose to utilize pavers in Upper Historic and Great Relief Hall. They also decided to utilize concrete walkways in Blacksnake, Spark's, and Little Bat Avenues. Fiberglass grates, for increased traction, were chosen for potentially slick surfaces at Richardson Spring and in River Hall.

Due to slopes with traction issues, several stairs were modified or added. New stairs and handrails are being added in Dante's Gateway and near Richardson Spring. In addition, existing stairs are being extended at the Steps of Time, Scotchman's Trap, and River Hall. The Steps of Time themselves are not being altered (due to their historic nature), but additional stairs are being added at the bottom to alleviate the slick slope on which they ended previously.

Portions of the Scotchman's Steps stairway are being altered and extended, but other portions are remaining intact. Hand rails are being modified or added at several slick areas and stairs. The unusual small steps

near Sidesaddle Pit are being replaced with a ramp with slip resistant concrete.

During review the need for and placement of lint curbs was extensively discussed. The team determined that lint curbs were appropriate for use in areas with demonstrated dust and lint problems. These areas included Upper Historic (including Little Bat Avenue), Great Relief Hall, and from Bandit's Hall through Spark's Avenue.

In addition, lint curbs are being used in the Grecian Bend area (before Fat Man's Misery) to act as retaining walls keeping sediment from migrating onto the trail. The team determined that, because there was no previously identified lint problem and because it would be very visually intrusive, lint curb was not needed in Blacksnake Avenue.

Trail Construction

Timing was (and remains) a crucial element of the construction project. The project was identified as requiring at least 18 months to reasonably construct. However, the park was concerned about having enough tour capacity for summer, if the Historic Tour was not available. So, the construction was divided into two segments.

The first construction season began in early September 2015 and will end just before Memorial Day weekend 2016. The second construction season begins in September 2016 and ends just before Memorial Day weekend 2017. How to best utilize those two seasons was left open to the contractor. The park will run Historic Tours during the summer between the construction periods.

In June 2015 the HTR trail construction project was put out for bid. The winning bidder was The Tradesmen Group, Inc. (Plain City, OH) (TTG). For handrails and

welding they employed a metal fabrication sub-contractor, On Time Fab, Inc. (Owensboro, KY).

The construction phase of the project began with a pre-construction meeting on September 1, 2015. TTG decided to divide the project into halves geographically for the two seasons. For the 2015-16 construction period, they chose to work from Methodist Church to Fat Man's Misery. For the 2016-17 period, they plan to work from Fat Man's Misery to Little Bat Avenue. The park was able to run Mammoth Passage tours into Rafinesque Hall on weekends and busy periods during construction during the 2015-16 period.

As of mid-March 2016, the construction project was on schedule. Concrete walkways and stairs have been largely completed in lower historic. Hand rails are being installed in that area. The paver trail and lint curbs in the Upper Historic Section are almost completed in Methodist Church and from the end of the previously existing paver trail to the area of the Martha Washington

light switch. Work remaining this season is centered on the no ground penetration area near Giant's Coffin and in the Wooden Bowl Room.

As with almost any project in the cave, this project has had its share of challenges. Archaeological materials and voids beneath the existing trail surface have led to modifications of some of the designed plans.

In addition, although the designs by VHB relied on the most complete cave survey available, when the trail was laid out for construction, we inevitably found areas where slight modifications would permit construction with less resource impact. The construction oversight team made decisions on these minor modifications in consultation with the contractor, VHB, the archaeologist, and park staff.

With the construction on schedule, we look forward to using the newly renovated portions of the HTR trails this summer and are already working with TTG in anticipation of next season's construction.

Quantitative Dye Studies to Evaluate the Spill Response System for Mammoth Cave National Park

JeTara Brown¹, Thomas Byl^{1,3}, Rickard S. Toomey, III², Lonnie Sharpe, Jr.¹

¹ Tennessee State University

² Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park

³ United States Geological Survey

Introduction

Mammoth Cave National Park is located in south-central Kentucky (Figure 1) has been designated an International Biosphere Reserve since 1990. The Park is home to the world's largest cave with over 400 miles of passages and a cave ecosystem that is linked to the surface through groundwater recharge. Groundwater quality in the Mammoth Cave region of Kentucky is critical to the cave's ecosystem, tourism, and the health of the Green River. Despite its vulnerability, groundwater is used as a vital resource to many communities around the world, including the United States. In fact, ground water is used as a source of water supply by about one-half the population of the United States. An estimated 11 percent of karst springs in Kentucky are used for domestic water supplies. This means over 10,000 homes rely on groundwater as their water supply source. These people have a critical interest in protecting the quality of the water they are drinking. Mammoth Cave National Park itself has a biodiversity of 43 mammals, 15 reptiles, 19 amphibians and 3 fish which all rely on the groundwater for survival.

The National Park Service controls the main part of the cave and encourages tourism while protecting the unique and fragile ecosystem in the cave. With over 500,000 visits per year, it is natural for accidents and spills to occur on the surface. Spills commonly come in the form of parking lot runoff due to the transport of auto diesel fuels through stormwater flow and broken sewer lines. Hence the Park's concern for maintaining high quantity contaminants from spills or wrongful release of chemicals. Therefore, it is important to develop a system that prevents the pollutants from harming the fragile cave ecosystem. Unfortunately, the same hydrogeologic processes that formed the cave makes the karst system vulnerable to contamination. Many of the natural storm-drainage flowpaths go directly to distinct sinkholes rather than the filters.

Resource Management Incidents

On May 27, 2014, a sewer line break occurred on Mammoth Cave Parkway near Green Ferry Road. According to Mammoth Cave National Park's After Action Report, the accident was caused by the failure of



Figure 1: Map of Mammoth Cave National Park

a two-inch brass ball valve. The ball valve failed when repairs were being made to resolve a much-smaller sewer leak that resulted from an air-relief valve that failed to shut properly. The air relief valve failure caused a small level of sewage spillage, and then the subsequent ball valve failure resulted in an initial sewage geyser that spouted approximately 20-30 feet high for a short period and then became a steady flow at ground level for over one hour before a repair was made. The Caveland Environmental Authority (CEA) employees and park employees responded by capping the geyser and placing check dams along the flow path. According to the CEA, approximately 5,000 gallons of sewage was spilled and that about 3,000 gallons were recovered.

In addition, a second sewage spill occurred at the same location on April 28, 2015 there was only steady flow of sewage detected. The cause and amount of sewage released has yet to be identified, but it is assumed to have been flowing for a long period of time. The need for containment basins within the park has increased. It is well known that preventing contamination of the groundwater is preferable to remediation. Therefore, the objective of this study was to measure the effectiveness of temporary check dams used to impede transport from a surface sewer leak into the cave.

Methods and Results

Three quantitative tracer studies were conducted from August 2014 to January 2015 to test the effectiveness of the check dams. The presence and absence of two temporary check dams constructed with pea-gravel were the main variables in the studies. Check dams are relatively small, temporary structures constructed across a swale or channel that are typically

constructed out of gravel, rock, sandbags, logs or treated lumber, or sediment retention fiber roll. Check dams can be temporary or permanent structures. Check dams are used to slow the velocity of concentrated water flows, a practice that helps reduce erosion. As stormwater runoff flows through the structure, the check dam catches sediment from the channel itself or from the contributing drainage area. A check dam either filters the water for sediment as it passes through the dam or retains the water, allowing the sediment to settle while the water flows over the dam. Multiple check dams, spaced at appropriate intervals, can be very effective. They are most effective when used with other stormwater, erosion, and sediment-control measures.

For the first test on August 31, 2014 (Figure 2), the rainfall depth was a 2.4 inch rain event. Two check dams were still in place along the surface flow routes. There was a tracer breakthrough in the cave 10 hours after the dye was released. Sixteen hours after the time of the release, approximately half of the recovered dye (center of mass) had moved past the monitoring station at Cataracts. The total amount of dye accounted for was approximately 4 mL out of the 180 mL released, which is less than 3% of the tracer used in this study. These results indicate that the dams did a great job retaining most of the dye on the surface despite the heavy rain.

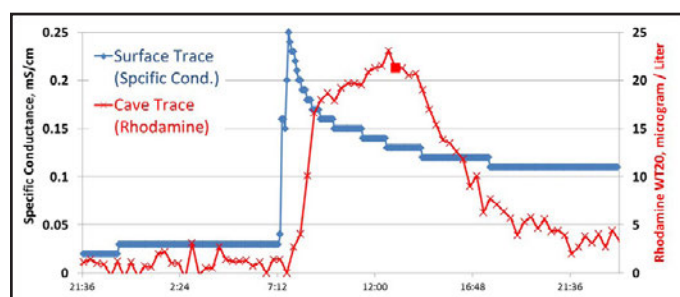


Figure 2: Breakthrough Curve for Test 1 conducted August 31, 2014

The second test (Figure 3) was initiated on the evening of October 13, 2014 during a 2.1 inch rain event. Both check dams had been removed for this study to estimate the amount of time it would take for the dye to reach the cave with no obstacles. The breakthrough and center-of-mass were calculated from the results. Breakthrough in the cave occurred 4 hours after the dye was released. The center of mass occurred 10 hours after the release time. The total amount of dye accounted for via concentration and discharge was 262 mL out of the 600 mL released (43%).

During the final tracer test on January 3, 2015 (Figure 4), the rain depth was 0.7 inches. Due to timing, the release of tracer was on the tail end of the storm instead of the rising limb like the other two tracer tests. Breakthrough in the cave occurred only 50 minutes after the time of release. The center

of mass was determined to be 15 hours after the time of release. The maximum tracer amount recovered was 288 mL of dye which was 48% of the total amount of dye released.

Conclusions

Based on these results, we can conclude that the dams increased mean residence time on the surface from approximately 0.83 to 16 hours, providing management more time to implement waste recovery. The dams also reduced the quantity of dye entering the cave by 90%. Temporary check dams provide emergency responders with an effective way to impede contaminants from entering the karst groundwater system at Mammoth Cave National Park. The dams are also aesthetically neutral for tourists, seeing that they are not overbearing to where they disturb the natural beauty of the surrounding environment. The limestone pea gravel used in the design is a natural material indigenous to the area geology, blending into its surroundings. More work needs to be done to identify and highlight surface to cave connections using GIS to anticipate sinkholes that are at risk of contaminants. One would also need to continue to test the dams to better understand the life expectancy. In the meantime, monitoring of the site and dam maintenance should be conducted continuously to retain effectiveness.

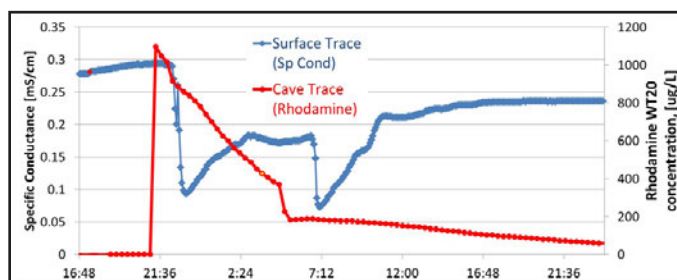


Figure 3: Breakthrough Curve for Test 2 conducted October 13, 2014

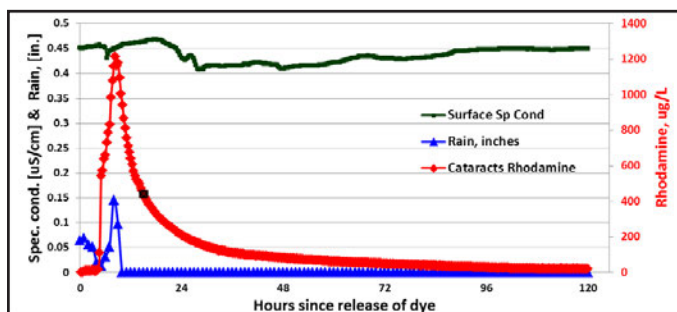


Figure 4: Breakthrough Curve for Test 3 conducted January 3, 2015

Continuing Measures in Response to White Nose Syndrome at Mammoth Cave National Park

Gina Zanarini¹, Natalie Anderson¹, Chris Clark¹, Laura Shultz¹, Rickard Toomey², Shannon Trimboli³

¹ Student Conservation Association, Mammoth Cave National Park

² Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park

³ Mammoth Cave International Center for Science and Learning, Ogden College of Science and Engineering, Western Kentucky University

Abstract

Since the arrival of White Nose Syndrome (WNS) at Mammoth Cave National Park (MACA) in January of 2013, park populations of some bat species have fallen 80%. In addition, changes in bat behavior have led to an increase in bat-human contacts and concerns about potential rabies transmission. For these reasons, actions to understand and combat this disease have become increasingly important. In conjunction with strategies already in place, a 2014 National Park Service (NPS) Disease Outbreak Investigation Team (DOIT) workshop developed additional measures that have been put into practice at MACA. These measures to improve human safety and monitor bat response to the disease included safer bat handling procedures, increased communication for public safety and education, better coordination of state and federal officials, and increased monitoring of bats. As seasonal daily monitoring data is recorded and our understanding of the disease implications grows, adaptive management strategies are being employed as needed.

Introduction

White-nose syndrome (WNS) at Mammoth Cave National Park (MACA) was first discovered in January of 2013. Measures to combat the disease and slow its spread into and at the park have been executed since 2008. In 2011 the initial responses were presented as a park wide management plan (Toomey and Thomas, 2011) that focused largely on efforts to keep the disease from coming to the park, monitoring for the disease presence, and initial responses to the arrival of the disease. Since the arrival of the disease, further strategies to address and monitor its presence and effects continue to be implemented.

The park is currently drafting a more compact revision of the management plan that focuses on on-going responses. Several

recent additional practices stem from the Disease Outbreak Investigation Team (DOIT) Workshop. The DOIT were invited to the park in December 2014 to evaluate the current situation and especially the challenges of White Nose Syndrome related to increased bat-human contacts stemming from changes in bat behavior due to WNS.

This interagency panel of experts identified four key management tasks that were addressed during the conference (Wong and Cherry, 2015):

- Conduct risk assessments for potential human-bat encounters
- Identify new/enhance existing prevention and response activities
- Identify other areas that require actions to be taken

- Develop communication and educational materials for park employees, external stakeholders and visitors

As of February 2015, these tasks had been extensively investigated and on-going actions are addressing them.

Park Response to WNS

This paper focuses on the changes to the park's response that have been made since the arrival of the disease in 2013, as well as, responses resulting from the DOIT report. Toomey and others (2013) provided a brief review of the park responses culminating in the arrival of the disease on park.

Post-tour walk-over bioremediation mats are one of the primary methods to prevent tourists who take walking tours of the cave from spreading spores of the fungus that causes WNS. The use of the bioremediation mats at the park started in 2011, when WNS was first identified in Kentucky. These mats consist of a 14-foot length of carpet and a 6-foot long foam mat with a cleaning solution that people walk across when they exit the cave. The short, carpeted ramp preceding the mats at the Historic entrance helps remove dirt and mud containing possible spores before walking across the mat.

The bioremediation mats have changed over time. Originally the mats were filled with a Lysol™ solution as described in the national WNS decontamination protocols. However, because of concerns about the potential for peoples' skin to come in contact with the solution and the fact that Lysol™ is not labeled for use on footwear, the park stopped using Lysol™ solution in the mats in 2014.

After a discussion of possible cleaning products to use in the mats, the park chose to use a Woolite™ solution in the mats. Woolite™ is safe for human skin contact and

can be used to clean footwear. In addition, Shelley and others (2013) found Woolite™ can kill the fungal spores that cause WNS.

Visitors are required to walk over the mats upon exiting the caves. Walking over the carpet and mat helps clean spores off visitors' shoes, and thus greatly reduces the potential that they could take WNS to other places.

As an important public safety and education tool, tour guides now give a short talk on WNS and also warn visitors about the dangers of contacting bats and ask that any bat contacts be reported to the rangers. This talk provides a chance to inform people about the impacts WNS has had on bat populations, to provide visitors with information on the importance of bats, and allows the park to make sure people get the important safety information about the dangers of bat-human contacts. In addition, signs warning the visitors to avoid contact with bats are displayed in the visitor center and at the cave entrance.

The numbers of human-bat contacts have increased at MACA since the arrival of WNS. In 2014, twelve people had contact with a bat on the park. Most of these people had a bat fly into them while they were in the cave. Eleven of the bat-human contacts occurred between February and April, in spite of the fact that the majority of park visitation is in the summer (the twelfth bat-human contact was in October). In 2015, the pattern repeated itself to some extent, with seven bat-human contacts between January and April and three in the summer.

The seasonal increase in bat-human contact suggests to us that the contacts are occurring because WNS infected bats are coming out of hibernation and some of these sick bats are accidentally flying into visitors in the cave.

This increase in bat-human contacts concerned park leadership and state and national public health officials. For this reason, Superintendent Craighead requested assistance from a NPS Disease Outbreak Investigation Team (DOIT) in late 2014. Their report became the basis of continued bat monitoring and of park response to bat-human contacts.

The DOIT discussions resulted in standardizing park response to bat-human contact incidents. When a bat-human contact is observed or reported, park staff provides immediate first aid. They then provide contact information for Kentucky state and NPS public health officials, so the person can discuss the contact and determine whether any rabies post-exposure prophylaxis is required. The park also records contact information for the person contacted by a bat and information about the circumstances of the contact. In addition, the park contacts public health authorities (Dr. David Wong, NPS-Public Health Service; Dr. Danielle Buttke, NPS One Health Program; and Dr. John Poe, Kentucky Cabinet for Health and Family Services) to alert them of the contact.

The DOIT suggested daily monitoring of bat numbers and their locations was needed, at least for toured areas, to see if we could determine under what circumstances bat-human contacts occur. Results of this monitoring could potentially predict when conditions are right for contacts and allow actions to avoid them.

Two interns were hired through the Student Conservation Association to conduct daily monitoring beginning January 2015. Due to the extensive amount of work, an additional two interns were hired for the 2016 season for a total of four 2016 winter bat monitoring interns. Primary duties include daily bat

monitoring activities, moving downed bats from areas of potential human contact, and reporting WNS behaviors and infected bats. Additionally, dead or moribund (near death) bats are collected, processed, and sent for testing.

Collected specimens are shipped to the National Parks Wildlife Health Branch in Fort Collins in cooperation with Colorado State University pathology lab, where they are tested for rabies and WNS. The park submits bats to the Southeastern Cooperative Wildlife Disease Study at the University of Georgia, if a bat potentially is a new county or species record for WNS. These partnerships are longstanding and in-line with interagency protocols.

As a result of the risk assessment aspect of the DOIT conference, it was determined that certain routes would be more prudent to monitor due to a higher probability for human-bat contact. A three tier system of monitoring caves was an aspect of the 2011 management plan at MACA that the DOIT utilized during their risk assessment.

Bats moving forward towards cave entrances is an aberrant behavior of WNS. To detect this type of behavior, entrance checks (Tier 3 monitoring) were instituted at Long Cave, Colossal Cave and Dixon Cave. A fifteen minute survey is conducted where the surveyors will watch for any flying bats, collect dead or moribund bats, and note the number of bats near the gate when a gate check is conducted. Additionally, temperature readings at the cave entrance and at the surface are documented, as well as, current weather conditions.

Tour trail monitoring and cave entrance checks occur on a variety of schedules depending on the area. They also varied by year, due to an increase in staffing in the winter/spring of 2015-16 (Table 1, 2).

Table 1: Cave entrance and tour route monitoring schedule for winter 2014-15.

First year (2014-2015) cave tour route surveys		
Route	Survey frequency	Mileage
Full Historic	Daily	2 mile loop
Domes and Dripstones	Every other day	¾ of a mile
Cleveland Avenue	Weekly	1 mile round trip
Great Onyx	Weekly	½ mile
First Year (2014-2015) Entrance Checks		
Route	Survey frequency	Mileage
Dixon Cave	Daily	n/a
Long Cave	Weekly	n/a

The major change between the 2014-15 and 2015-16 monitoring seasons was the alteration in the Historic tour route. The Historic tour route is under construction (2015-2016) which has led to an increase in Domes and Dripstones tours to account for the lack of Historic tours run during the winter.

At the beginning of the season, the Historic short route was monitored twice a week and a Historic full route once per week. Due to noise concerns from construction that was occurring near a known Indiana bat (a federally endangered species) winter roost, the decision was made by the Science and Resource Management division to return to daily monitoring of the short route.

While the majority of the surveillance is conducted through Science and Resource Management, opportunistic surveillance is also utilized. By employing interdivisional cooperation, tour guides and other park employees are asked to inform their shift supervisors of any bat activity or dead/moribund bats while conducting their

daily duties. The shift supervisors relay the message to Science and Resource Management where the information can be properly documented for future reference. A binder with data sheets for employees to record where and when they had seen a flying bat(s) were placed in each division within the park.

Another recommendation from the DOIT was to have “bat kits” placed along toured routes so that problematic or moribund bats could be handled safely and efficiently. Kits were put in extra-large Ziploc™ bags (or in hard plastic tubs if subjected to woodrat damage) and placed in conjunction with first aid kits along toured routes for easy access.

The kits include a collapsible net to place over a distressed or downed bat on the ground, gloves and tongs to handle or pick up dead bats, and smaller Ziploc™ bags

Table 2: Cave entrance and tour route monitoring schedule for winter 2015-16.

Second year (2015-2016) cave tour route surveys		
Route	Survey frequency	Mileage
Full Historic	Weekly	2 mile loop
Short Historic	Daily	1 mile
Domes and Dripstones	Daily	¾ of a mile
Cleveland Avenue Entrance Stairs	Daily	250 ft
Cleveland Avenue	Weekly	1 mile round trip
Great Onyx	Weekly	½ mile
Second year (2015-2016) cave entrance checks		
Route	Survey frequency	Mileage
Dixon Cave	Daily	n/a
Long Cave	Weekly	n/a
Colossal Cave	Biweekly	n/a

plus a marker to write pertinent information on the collection bag. Light sticks are an additional item included in the kit to place beside the net covering a moribund or dead bat if whoever found it was not comfortable with placing the specimen in a bag. An information sheet with the bat handling procedure was also included.

With safety being of paramount importance, it should be noted that only people with rabies pre-exposure vaccinations would use these kits on live, active bats. While any employee is able to handle dead or moribund bats and move them off trail wearing the proper PPE included in the kit, they are allowed to decline the duty and report it to the bat interns for addressing according to their comfort level. For instance, a person without the vaccination could trap a moribund bat with the net, but actual handling would be left to those with rabies pre-exposure vaccinations.

Employees throughout the park divisions were selected to receive rabies shots or boosters so that every division has a representative who could handle potentially rabid animals, including bats, if needed. A total of thirty one employees in the park now have these vaccinations/boosters.

A WNS resource binder is also available to educate other park divisions and staff about the disease, its spread, and how the park was addressing the issue. The binder is updated as new information and studies regarding WNS are published. The availability of this resource binder, in addition to the efforts by the Interpretation division to inform the public, directly addresses the final task from the DOIT conference to develop communication and educational materials for visitors, external stakeholders, and park employees.

Conclusion

Moving forward, education and outreach efforts will remain of paramount importance and will be continued in an attempt to preserve areas untouched by WNS and teach visitors the importance and value of bats. Systematic winter monitoring conducted by interns from the Student Conservation Association will also remain important as a key contribution to daily observations.

Mammoth Cave National Park has been responding to WNS since 2008. This response has varied with changing circumstances, and it has become more intense since the arrival of WNS on park in 2013. In the future, the park will continue to use adaptive management strategies to combat other issues as they arise.

References

- Shelley, V., Kaiser, S., Shelley, E., Williams, T., Kramer, M., Haman, K., Keel, K. and Barton, H. 2013. Evaluation of strategies for the decontamination of equipment for *Geomyces destructans*, the causative agent of White-Nose Syndrome (WNS) J. CAVE. KARST. STUD. 75(1):1-10.
- Toomey, R. and Thomas, S. 2011. Mammoth Cave National Park White-nose Syndrome Response Plan.
- Toomey, R.S., Thomas, S.C., Gillespie, J., Carson, V. and Trimboli, S.R. 2013. White-nose Syndrome at Mammoth Cave National Park: Actions before and After Its Detection. Mammoth Cave National Park's 10th Research Symposium: Celebrating the Diversity of Research in the Mammoth Cave Region. 206-207.
- Wong, D. and Cherry C. 27 February 2015. MACA WNS DOIT Final Report. 3-8.

Use of Multiphysics Simulation to Model Environmental Conditions Associated with Bat Hibernacula including Preliminary Indication of Impacts on Saltpetre Vats in Mammoth Cave

Aaron Bird¹, Rick Olson², Rick Toomey³, Aaron Addison⁴, and Rachel Bosch⁵

¹ CD-adapco

² Science and Resources Management Division, Mammoth Cave National Park

³ Mammoth Cave International Center for Science and Learning, Mammoth Cave National Park

⁴ Scholarly Services, Washington University in St. Louis

⁵ Cave Research Foundation

Abstract

As a historically and biologically significant feature, the Mammoth Cave System has seen many changes due to human activity that have resulted in known and unknown changes to environmental conditions present in the cave. While the historical and archaeological records reveal much about these changes, the actual environmental conditions present can be difficult to describe. In our work, multiphysics simulation is used to recreate environmental and physical conditions that may have existed before changes were made to the natural state of the cave system. In addition, simulation is used to predict what may happen if further changes are made to the system in the future. Using 3-dimensional laser-imaging detection and ranging data (LIDAR) as a geometric representation of the historic section of Mammoth Cave combined with computational fluid dynamics simulations, the current work serves to demonstrate the thermal and airflow conditions that would have been present in a former (now abandoned) bat-hibernation colony in the Vespertilio area near Audubon Avenue. The model is then extended as a preliminary indicator of the humidity and thermal impacts that maintenance of conditions conducive to bat hibernation may have on airflow patterns in and around historically significant saltpetre vats in the main section of the cave.

Modeling Activity of the Indiana Bat (*Myotis sodalis*) at Mammoth Cave National Park Using Remotely-Sensed Descriptors of Forest Canopy Structure

Dodd, L. E.¹, N. S. Skowronski², M. B. Dickinson², L. K. Rieske³, and M. J. Lacki⁴

¹ Department of Biological Sciences, Eastern Kentucky University

² Northern Research Station, US Forest Service

³ Department of Entomology, University of Kentucky

⁴ Department of Forestry, University of Kentucky

Abstract

We sought to identify forest canopy characteristics useful for predicting activity of the Indiana bat (*Myotis sodalis*), an endangered species found at Mammoth Cave National Park (hereafter, the Park). To do so, we used Airborne Laser Scanning (ALS) to quantitatively describe understory, mid-story, and canopy structure across the Park (Dodd et al. 2013). Concurrent with the collection of remotely-sensed data, we conducted surveys for bat activity from August 2010 through October 2011 using acoustic detectors (Anabat II) deployed along geo-referenced transects (Dodd et al. 2013). These acoustic surveys were conducted before the detection of White-nose Syndrome at MACA (USNPS 2013).

Analysis of acoustic data was carried out using Echoclass v.1.1, and echolocation pulses classified as belonging to the Indiana bat were considered per detector / night as our response variable. We then derived a suite of forest canopy descriptors for our acoustic survey points using the ALS data set. This suite of variables incorporated descriptors based on the absolute measurements of ALS hits at 10-m increments throughout the forest canopy, as well as measurements for total canopy height and canopy gap. Our suite also incorporated predictive variables developed by Lesak et al. (2011), which apportioned the incidence of ALS hits throughout the forest canopy by collapsing ALS data into 10 proportionate bins scaled to the height of the canopy. All descriptors were based on a 15-m radius centered on an acoustic survey point.

These descriptive variables included:

- Total Density (sum of all ALS-derived CHP from the ground to the top of the canopy)
- Gap Index (percent of open air space >3 m in height without vegetative structure)
- Canopy Height (height of canopy at the 90th percentile of ALS hits aboveground)
- Understory Density (sum of ALS-derived CHP from the ground to 10-m aboveground)
- Midstory Density (sum of ALS-derived CHP from 10 to 20-m aboveground)
- Overstory Density (sum of ALS-derived CHP from 20 to 30-m aboveground)
- Legacy Density (sum of ALS-derived CHP > 30-m aboveground)

- $P_{\text{Understory}}$ (percent of ALS-derived CHP in the bottom 2 bins of scaled data)
- P_{Midstory} (percent of ALS-derived CHP in intermediate 3rd through 6th bins of scaled data)
- P_{Canopy} (percent of ALS-derived CHP in the upper 7th through 10th bins of scaled data)
- $R_{\text{Understory}}:\text{Midstory}$ (ratio of $P_{\text{Understory}}$ to P_{Midstory})
- $R_{\text{Understory}}:\text{Canopy}$ (ratio of $P_{\text{Understory}}$ to P_{Canopy})
- $R_{\text{Midstory}}:\text{Canopy}$ (ratio of P_{Midstory} to P_{Canopy})
- $R_{\text{Total}}:\text{Understory}$ (ratio of total density to understory density)

We used multiple linear regression in conjunction with Akaike's Information Criterion (AIC) model rankings (Burnham and Anderson 2002) to identify the most parsimonious models for predicting activity of the Indiana bat. We derived *a priori* canopy structure models to be evaluated for the response variable. These models corresponded to specific portions of the forest canopy (understory, midstory, and overstory), as well as a model describing the entirety of clutter (hereafter, "total clutter").

Component predictor variables for the models were as follows:

- total clutter: total returns, gap index, canopy height
- overstory: overstory density, legacy tree density, P_{Canopy}
- midstory: midstory density, P_{Midstory} , $R_{\text{Understory}}:\text{Midstory}$, $R_{\text{Midstory}}:\text{Canopy}$
- understory: understory density, $R_{\text{Total}}:\text{Understory}$, $P_{\text{Understory}}$, $R_{\text{Understory}}:\text{Canopy}$

We used AIC scores relative to the smallest AIC value (ΔAIC) and Akaike weights (w_i) to assess the suitability of habitat models (Burnham and Anderson 2002, Arnold 2010). For models with strong support, we identified significant parameter estimates to elucidate which canopy descriptors within a model best described the variation observed for activity of the Indiana bat.

In summary, a total of 836 detector-nights from 109 survey locations were used for model development. From these, 35,872 echolocation files were recorded and 790 files were classified as belonging to the Indiana bat. Resulting models were significant for total clutter, understory, midstory, and overstory (Table 1).

Table 1: Akaike's Information Criterion scores (AIC), difference in AIC values (ΔAIC), Akaike weights (w_i), and number of parameters (K) developed for multiple linear regressions modeling activity of the Indiana bat (*Myotis sodalis*) using ALS-derived descriptors of vegetation throughout the forest canopy at Mammoth Cave National Park, 2010-2011. Models with an asterisk were significant ($P \leq 0.05$).

Response Variable	Model	AIC	ΔAIC	w_i	K
Indiana Bat Pulses (n = 836 detector-nights)	Understory*	7525.05	0.0	0.99	6
	Midstory*	7537.94	12.9	< 0.01	6
	Overstory*	7541.34	16.3	< 0.01	5
	Total Clutter	7546.81	22	< 0.01	5

Considering AIC rankings, however, only the understory model received support. Parameter estimates of this model suggest the Indiana bat was more active in areas with proportionately less clutter in the understory (Table 2). Based on these data, we would hypothesize that management activities that promote a long-term reduction of understory clutter (e.g., prescribed fire or silvicultural thinning) will complement efforts to provide useful foraging habitat for this endangered species.

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Literature Cited

- Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. *Journal of Wildlife Management* 73: 214-225.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multi-modal inference: a practical information-theoretic approach. Second Edition. Springer, New York, New York, USA.
- Dodd, L. E., N. S. Skowronski, M. B. Dickinson, M. J. Lacki, and L. K. Rieske. 2013. Using LiDAR to link forest canopy structure with bat activity and insect occurrence: preliminary findings. Pp. 50-57 in *Proceedings of Mammoth Cave National Park's 10th Research Symposium* (S. R. Trimboli, editor). Mammoth Cave National Park, Mammoth Cave, Kentucky.
- Lesak, A. A., V. C. Radeloff, T. J. Hawbaker, and A. M. Pidgeon. 2011. Modeling forest songbird species richness using ALS-derived measures of forest structure. *Remote Sensing of Environment* 115: 2823-2835.
- U. S. National Park Service. 2013. Mammoth Cave National Park News Release: White-Nose Syndrome Confirmed in Park Bats. Retrieved from https://www.whitenosesyndrome.org/sites/default/files/files/nr_-_maca_wns_announcement_-_final.pdf. Accessed February 2, 2016.

Table 2: Parameter estimates (β) and standard errors (SE) for ALS-derived descriptors of the forest canopy used in models of bat activity (Indiana bat pulses) at Mammoth Cave National Park, 2010-2011. Parameter estimates indicated by an asterisk were significant within a model ($P \leq 0.05$).

Model	Canopy Descriptor	$\beta \pm SE$
Total Clutter	Total Density	2.7 ± 5.1
	Gap Index	95.2 ± 57.3
	Canopy Height	$2.4 \pm 0.8^*$
Overstory	Overstory Density	-1.8 ± 7.2
	Legacy Tree Density	$140.4 \pm 37.4^*$
	P_{Canopy}	-20.4 ± 19.3
Midstory	Midstory Density	-2.7 ± 6.1
	P_{Midstory}	-72.7 ± 44.9
	$R_{\text{Understory}}^2 \text{ : Midstory}$	-1.4 ± 1.3
	$R_{\text{Midstory}}^2 \text{ : Canopy}$	$30.0 \pm 7.7^*$
Understory	Understory Density	-19.2 ± 11.1
	$R_{\text{Total}}^2 \text{ : Understory}$	-2.5 ± 48.9
	$P_{\text{Understory}}$	$-172.2 \pm 44.6^*$
	$R_{\text{Understory}}^2 \text{ : Canopy}$	$46.5 \pm 8.4^*$

What Data Analytics Can Do for You!

Leyla Zhuhadar¹, Kirk Atkinson¹, Albert Meier², and Ouida Meier²

¹ WKU Initiative for Applied Data Analytics, Western Kentucky University

² WKU Green River Preserve, Department of Biology, Western Kentucky University

Abstract

In this presentation, we describe how the WKU Initiative for Applied Data Analytics (ADA) can play a key role in helping YOU as a business organization or an environmental research entity make sense of YOUR data and how to best utilize it. As an example, we will present our first grant proposal entitled “*Designing and Implementing a Cloud-based Repository for the WKU Green River Preserve: Moving from Entrenched Data Structure to Semantic Web.*” The ADA Initiative recently offered his research services in Data Mining and Predictive Analytics to WKU Green River Preserve (GRP). Dr. Albert Meier (Executive Director of the GRP) and Dr. Ouida Meier have decades of experience and honorable efforts to host numerous projects focused on the Preserve or included it as a study site in a larger project. Through a grant proposal, we are planning to work with Dr. Meier to capture, organize, store, and release various types of datasets that are being accumulated and that are growing at an accelerated rate at the Green River Preserve (GRP). In this presentation, we will describe what Data Analytics can do for GRP and/or for YOU!

Introduction

The GRP is an ideal location from which to study the ecology of the Green River watershed, home to high biological diversity and one of earth’s best developed karst systems.

The goal for this research project is to capture, organize, store, and release various types of datasets that are being accumulated and that are growing at an accelerated rate at the Green River Preserve (GRP). The GRP hosts numerous projects, and in the process, data is generated for monitoring, land management activities, visitor-ship, plant and animal occurrences, and GIS mapping layers. These datasets must be carefully structured, recorded, stored, and made thoughtfully accessible to maximize benefit to researchers for further research, education, conservation, and outreach. This is true for both near term and for longitudinal research usefulness.

The valuable lessons learned in this project will be readily applied by investigators and involved students to other fields of data work, and the resulting information structures will provide a stable repository for additional projects, classes, research, and community outreach. The repository will be extremely valuable to investigators in multiple fields seeking grants to support work using the GRP, and so will be an essential element in assuring long-term financial sustainability of the GRP. The information structures will also be of interest to other stations, parks, and sites where conservation, research and education are primary goals, and where reliable documentation of environmental conditions and biota are essential to detecting changes over time.

The goal for this project is to automate the process of capturing, organizing, storing, and releasing various types of datasets that

are being accumulated and that are growing at an accelerated rate at the Green River Preserve. Several specific areas of data challenge are described in the next sections.

Background and Related Work

The Western Kentucky University Green River Preserve (<http://www.wku.edu/greenriver/>) has a mission to foster knowledge and protection of our highly biodiverse region and natural heritage through research, education, and conservation. The Green River Preserve (GRP) is now over 1,500 acres. It includes 7 miles of river frontage and helps protect 12 endangered species of mussels, cave shrimp, bats, and many other species and habitats. This remarkable place has generated enormous benefits for WKU in multiple areas of research, education, conservation, and service, as following:

- **Research:** Since the opening of the Preserve in 2004, 11 peer-reviewed publications, 12 master's theses, 7 undergraduate honors theses, and over 90 presentations at conferences have focused on the Preserve or included it as a study site in a larger project.
- **Education:** A broad range of classes, labs and field trips from several departments are held at the GRP in biology, geology, architecture, folk studies and anthropology, K-12 classes, and visiting classes from other universities. Many of the students in these classes participate in research projects as well
- **Conservation:** Dr. Albert Meier was awarded the first annual Stewardship Award in 2010 by the KHLCFB for management of the GRP, and the 2012 Biological Diversity Protection

Award from the KSNPC. GRP terrestrial habitats are very diverse, and the Green River that flows through it hosts over 150 fish and 71 mussel species, and ranks 4th in the US in imperiled fish and mussel species.

- **Service:** The GRP hosts training experiences for rescue squads, conservation agency training, scout camping, non-profit group retreats, hiking and canoeing groups, and an annual deer management hunt by wounded soldiers and weekend summertime canoe retreats for the veterans and their families.

Future Directions

A new plan has been proposed for the future of the Preserve that increases research, teaching, outreach, and support of local economic development. This past year we were able to hire a part-time land manager and partially fund two director positions, and plan to develop additional facilities to support research and education. In the long term, we hope these efforts will help the GRP function similarly to a Long-Term Ecological Research site, where the value of prior work increases with time.

Proposed Research Idea

Green River Preserve has numerous datasets; these datasets must be carefully structured, recorded, stored, and made thoughtfully accessible to maximize benefit to researchers for further research, education, conservation, and outreach. This is true for both near term and for longitudinal research usefulness.

The goal for this research project is to automate the process of capturing, organizing, storing, and releasing various types of datasets that are being accumulated

and that are growing at an accelerated rate at the Green River Preserve. Operations, management, research, teaching, and other projects at the Green River Preserve pose layers of distinct challenges in data aggregation, structuring, management, analysis, and mining. Several specific areas of data challenge are described below.

Environmental sensor monitoring data

At the GRP is being collected on a near-continuous (every 3 minutes) basis, and is downloaded monthly. Attributes of weather and soil sensor stations include date, time, air temperature, relative humidity, sunlight available for photosynthesis (PAR), and soil moisture. There are currently 5 such weather and soil sensor stations over the 1,520 acres of the GRP, plus 3 additional weather stations with only temperature and relative humidity data. There is a need to develop standard procedures for documenting instruments, retrieving data, cleaning, archiving and serving raw or minimally processed data to researchers and classes for long-term projects and for context in short-term projects and studies, as well as for potential data exploration procedures (e.g., site comparison, time series analysis, heterogeneity analysis, and other patterns through analytical and data mining procedures. After developing a workable prototype, we would like to expand the data array to include additional environmental sensors and images from security cameras and game cameras as well. Through a server, some data sets could be made open to the public, and others might require login to retrieve more restricted data.

Biological baseline data

At the GRP includes species lists by tract when acquired, as part of standard management requirements from the

Kentucky Heritage Land Conservation Fund Board (KHLCFB) who funded purchase of these land tracts. Species lists from biological surveys at a minimum include plants, fish, amphibians, reptiles, birds and mammals. While some groups such as plants have their distributions mapped at the community level, or as a species in the case of invasive exotics that require our efforts toward eradication, others can only be identified by tract (it is illegal to give public notice of the precise locations of federally endangered species where that information might lead to harvesting of protected organisms). GRP species lists are on deposit with the KHLCFB, and in simplified form online at DiscoverLife.org.

Project data Management

This data is needed to document information collected within numerous research and conservation projects, biological restoration and management. In addition to the environmental sensor data and baseline biological data already mentioned, project data is also generated for monitoring, land management activities, plant and animal occurrences, and GIS mapping layers. Our research agreement collects and stores project proposal data, and includes a commitment by individuals conducting research to share raw data and subsequent analyses and publications with the GRP. However, we do not yet have a suitable architecture for collecting and housing data and analyses at the project's end beyond deposit of submitted files into a restricted-access directory on a WKU cloud-based, shared drive. Data standards have been developed by national organizations, which oversee collection and management of ecological data sets, and we should review, adopt, and publicize to our partners' appropriate data standards.

Business and financial data

Data management is needed to reliably schedule and document visitor days and categories, determine costs and potential revenue sources. These datasets are not only essential for managing the GRP appropriately and efficiently, they also are nearly always requested by funding sources, from NSF's facility development funding for field stations to local donors who want to know where their contributions will go and what their money will be spent on.

Client data

Client data is an important category for maintaining long-term relationships with people who visit or use the GRP and feel connected to it. This is currently maintained as a spreadsheet of contact information including email addresses, but more is needed to maintain connections, recruit volunteers, select people to remind of specific upcoming opportunities, pursue grants with our partners (from K-12 teachers to wounded veterans' groups), track interaction sequences, add to event invitation lists, and solicit donations from when appropriate – people are the network for the lifeblood of the Preserve, and the basis for long-term sustainability. We need to keep in better contact with individuals we encounter in a myriad of roles, locations, and events who have an interest in the GRP.

Daily work data

These data need to be tracked: progress on projects; student worker and other employee accomplishments; visits and security issues; work, time, and travel required as preparation for events or class visits or new projects; and visitor accommodation. We currently use sign-in sheets at the main entrance to the GRP to track this information, but the method leaves out trips

to other sections of the GRP (north side, Lawler Bend, WKURF tract) and does not provide a way to cross-tabulate results for better categorical summaries.

Security Data

Currently, spreadsheets are used for tracking, issuing, changing, and reclaiming labeled keys and electronic access codes, and who has been granted access for which time windows, is closely related to work data, project data, and client data. It makes sense to restructure this information and make it more accessible comprehensive, and able to be summarized and cleanly modified or tracked as changes occur.

Specific Outcome of the Project

The specific outcome of the project will be a comprehensive system design for capturing, storing, and making available data for the Green River Preserve. The system design can be implemented in modules, as needed and as funding becomes available. As a test of the design, the modules for environmental monitoring data and biological baseline data will be populated and subjected to a range of analyses and data mining explorations to assess how the systems perform, and whether the databases themselves require additional fields or metadata in order to be useful for multiple research, teaching, and conservation projects over the long term.

Conclusion

The project proposed is important on several scales. Developing plans for managing and fully using data will increase the value of the GRP to WKU, and to all who visit and work there for decades to come. The GRP offers opportunities for research and education, and also and plays an extremely important role in preserving biodiversity at the regional, state, and national levels. There remains a

highly engaged community that contributes to the GRP as well as benefits from the GRP, and the Preserve offers unique opportunities for interdisciplinary work. The GRP is coming of age at a time when capture and use of data, including defining underlying structures and subsequent model development, is in a golden age. The ADA Initiative will consult data structures and methods developed earlier for other sites, but ideally the structure of data is optimized for the queries and models that will come from it. With more user-friendly data mining, data visualization, and data exploration techniques recently available, data management plans will be designed to meet the needs of current and future uses that we would not have imagined a decade ago. Structuring our full range of conservation,

research, education, and service activities within a long-term data management design could offer the chance to share our unique solutions with other stations. A data management and deployment design would accelerate our productivity and our synergism among conservation, research, education and outreach work, as well as interactions between disciplines.

References

WKU Green River Preserve, Research Use Form. Last modified 2014. http://www.wku.edu/greenriver/forms/research_app.php

WKU Upper Green River Biological Preserve, Discover Life. Last modified Aug. 2010. http://www.discoverlife.org/nh/cl/US/KY/Hart/WKU_Green_River_Preserve/

The Max Kämper Map of Mammoth Cave: An NPS Centennial Restoration

Tres Seymour¹

¹ Visual Information Specialist, Mammoth Cave National Park

Introduction

German engineer Max Kämper's 1909 map of Mammoth Cave was a major achievement in subterranean cartography and continues to find use today as a guide to the famed labyrinth and as a touchstone for modern cave survey in the Mammoth Cave system. Kämper's original, however, has deteriorated over time and with frequent exposure due to the needs of researchers, and some of its features are on the verge of disappearing. The green and blue inks, in particular, are fading almost to the point of illegibility, threatening to take Kämper's knowledge with them. This discussion documents the five-year effort, from 2011 to 2016 to digitally "remaster" the Max Kämper map as a project to both provide researchers unprecedented access to the map's contents, and at the same time preserve both the knowledge of the contents and protect the fabric of the original for future generations – an outcome that defines the purpose of the National Park Service as it celebrates its Centennial.

Methodology

Illustration and exposition will include analysis of the current state of the original, choice and rationale of methods for digital restoration, and techniques used to ensure the greatest possible fidelity to the original document. The methodology was based primarily on principles of scientific analysis related to the results of digital imaging of the original, and the information that could be gleaned from computer processing of that imaging to "turn back the clock" on some of the worst depredations of time on paper and ink. At the same moment, however, consideration was given to aesthetic and human factors to ensure that the restoration retained the sense and spirit of a document created by the hand of a remarkable individual. The explication of the methods used rationalizes the attempt at balance between science and art.

Findings and Recommendations

While this presentation is largely intended as documentary to the restoration of the map, it does include commentary on discoveries made during restoration, and recommendations for the future. Post-processing of digital map scans revealed a number of unexpected map details that give insight into Kämper's cartographic methods, his handwriting, and other matters. These are included in the map data as an "Anomaly Layer" for researchers to comb for information.

In light of the wealth of information the restoration and the original scan data provides to researchers, as well as the mandates of NPS responsibilities under the Organic Act, this work also takes a position on the disposition of the original document from this point going forward and makes a formal recommendation to Park Management.



Celebrating the Diversity of Research in the Mammoth Cave Region

**11th Research Symposium
at Mammoth Cave National Park**

Schedule of Events

April 18-20, 2016

Mammoth Cave National Park Training Center

MONDAY, APRIL 18

- 8:00 Informal meet and greet, registration, load talks
- 8:30 Welcome, Special Opening Event
- 9:00 Ethnographic Overview and Assessment of Mammoth Cave National Park: A Progress Report
~ Michael Ann Williams, Kristen Clark, Eleanor Hasken, and Rachel Haberman
- 9:45 Break
- 9:55 Where Did They Go? An Analysis of Out-Migration from Mammoth Cave National Park During Creation
~ Collins Eke
- 10:20 Flint Ridge Cave History and Legends
~ Norman L. Warnell and Stanley D. Sides
- 10:45 Research and Resources in WKU Special Collections
~ Nancy Richey
- 11:10 Announcements
- 11:15 Lunch - on your own
- 12:45 Civilian and Soldier Graffiti of Hundred Dome (Coach) Cave, Kentucky, 1859 -1862
~ Marion O. Smith and Joseph C. Douglas
- 1:10 Archeological Excavations in Advance of the Historic Tour Trail Rehabilitation
~ Steven Ahler and Rebecca L. Hummel
- 1:35 Documentation and Conservation of the 1812-Era Saltpeter Works in Mammoth Cave, Kentucky
~ George M. Crothers and Christina A. Pappas
- 2:05 Break
- 2:15 Recent Investigations at 15Ed23: Historic and Cultural Resources in a Disturbed Cave Environment
~ Joseph C. Douglas, Alan Cressler, George Crothers, Marion O. Smith, Kristen Bobo, and Justin Carlson
- 2:40 1852 Journey to Mammoth Cave StoryMap
~ Katie Algeo
- 3:05 Announcements
- 3:10 Break, Poster setup
- 3:25 - 5:00 Poster session
- 7:00 Mammoth Cave: A Place Called Home (Held at the Cave City Convention Center)
~ Cheryl Beckley, WKU PBS

POSTER SESSION

Archeology / History

- Evaluation of an Early Nineteenth Century Brick Kiln at the Gardner House in Hart County, Kentucky
~ Lauren Kenney and Darlene Applegate
- New Discovery Cultural Artifact Inventory and Analysis Project Update
~ David Kime, Jillian Goins, Robert Jensen, Clayton Johnson, Alessa Rulli, and Victoria Voss

Biology / Ecology

- Oak Regeneration in Mammoth Cave National Park
~ Bill Moore and Carl Nordman
- Surveys for the Diamond Darter (*Crystallaria cincotta*), an Endangered Species Known Historically from the Green River in Kentucky
~ Matthew R. Thomas and Stephanie L. Brandt
- 12 Years Conducting MAPS at Mammoth Cave National Park: What Have We Learned?
~ Brice Leech
- Recent Winter Bat Numbers at Mammoth Cave National Park: Pre/Post White-Nose Syndrome Arrival
~ Steven Thomas
- The Effects of the Fungus *Beauvaria* sp. on the cave cricket, *Hadenoeus subterraneus*
~ Christina Walker, Derrick Jent, and Claire Fuller

Education / Interpretation

- Chronicling Mammoth Cave Data Visualization
~ Matthew Beckerich, Jared Koshiol, Noah Love, Greta Lowe, Celeste Shearer, and David Kime
- Youth Engagement in Public Health at Mammoth Cave National Park: A Pilot Alternative Spring Break Program
~ Laura Shultz, David Wong, Amy E. Thomas, Rick Toomey, and Shannon Trimboli
- Six Americas: Where Do Teachers Stand
~ Jeanine Huss and Cheryl Messenger

Geology / Hydrology

- Drainage to Mammoth Cave National Park
~ Chris Groves, Katie Algeo, and Laura Myers
- Clastic Sediments in Karst as a Vehicle for Contaminant Transport: Lithofacies and Transport Mechanisms
~ Rachel Bosch and William B. White
- Green River Alluvial Terraces at Mammoth Cave and Glacial Valley Trains on the Ohio River: Genetic Correlation Revisited
~ Joseph A. Ray
- Spatial Distribution Map of Small Caves within Mammoth Cave National Park
~ Bill Copeland

Resource Management

- Meta-Analysis of Research Conducted at Mammoth Cave National Park, 1980-2013
~ Andrea Bachman, Nicole Erb, Ellen McPhillips, Matthew Rice, Tawni Riker, and David Kime
- Exploration of Mammoth Cave Pools with Submersible Remotely Operated Vehicles
~ S. Altenstadter, O. Hennis, C. Johnson, A. Willett, S. Hammer, and E. Wong
- Redevelopment of Historic Tour Cave Trails
~ Rickard S. Toomey III and Steve Kovar
- Continuing Measures in Response to White-nose Syndrome at Mammoth Cave National Park
~ Gina Zanmarini, Natalie Anderson, Chris Clark, Laura Shultz, Rickard Toomey, and Shannon Trimboli

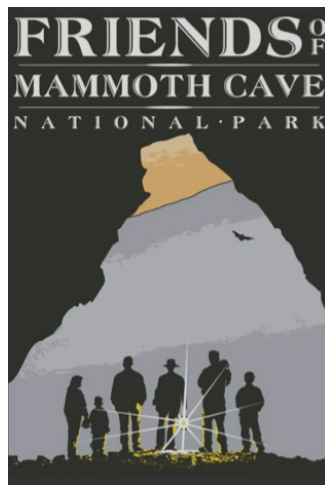
TUESDAY, APRIL 19

- 8:00 Informal meet and greet, registration, load talks
- 8:30 Welcome
- 8:40 The Freshwater Mussels and the Green River: Conservation, Protection, and Management of a Vital Resource in North America
~ Monte McGregor, Bobby Carson, and Ken Kern
- 9:05 In Situ Survival and Performance of Juvenile Mussels in Streams and Correlations with Water and Sediment Quality Factors
~ Wendell Haag, Jacob Culp, Monte McGregor, James Stoeckel, and Robert Bringolf
- 9:30 Potential Evidence for Arsenic Mineralization in Mussel Shells in the Upper Green River Basin, Kentucky
~ Autumn Turner, Chris Groves, Aaron Celestian, and Albert Meier
- 9:55 Break
- 10:10 Host-Parasite Associations of Small Mammal Communities: Implications for the Spread of Lyme Disease
~ Matthew Buchholz and Carl Dick
- 10:35 Amphibians and Reptiles of Mammoth Cave National Park: What Have We Learned After 13 Years of Monitoring
~ John MacGregor
- 11:00 Over Half a Century of Mammoth Cave National Park Mid-winter Bird Count Data
~ Blaine Ferrell
- 11:25 Announcements
- 11:30 Lunch - on your own
- 1:00 The Effects of Rainfall on Vernal Herbs
~ Janis LeMaster and Albert Meier
- 1:25 Conducting a Biological Inventory of Sloan's Crossing Pond
~ Miranda Thompson, Jason A. Matthews, and Christy Soldo
- 1:50 Video Presentation: Monitoring Cave Organisms, Cumberland Piedmont Inventory and Monitoring Network
~ Kurt Helf, Steven Thomas, and Michael Durham
- 2:15 Break
- 2:25 The Activity of *Myotis sodalis* and *Myotis septentrionalis* Changes on the Landscape of Mammoth Cave National Park Following the Arrival of White-nose Syndrome
~ Rachael Griffiths, Luke E. Dodd, and Michael J. Lacki
- 2:50 Summary of 2015 Winter Bat Monitoring at Mammoth Cave National Park
~ Laura Shultz, Chris Clark, Rick Toomey, and Shannon Trimboli
- 3:15 Evaluating the Energetic Value of Lepidoptera Using Bomb Calorimetry
~ Shelby A. Fulton, Luke E. Dodd, and Lynne K. Rieske
- 3:40 Break
- 3:50 Organization and Development of the Eyes of *Ptomaphagus hirtus*, the troglobitic small carrion beetle of Mammoth Cave
~ Markus Friedrich, Jasmina Kulacic, and Elke Buschbeck
- 4:15 Strip Adaptive Cluster Sampling with Application to Cave Crickets
~ Kurt Lewis Helf, Tom Philippi, Bill Moore, and Lillian Scoggins
- 4:40 Cave Research Activities in and around Mammoth Cave National Park
~ Pat Kambesis and Bob Osburn
- 5:05 Announcements
- 7:30 CRF map salon and social (Held at Hamilton Valley Research Facility)

WEDNESDAY, APRIL 20

- 8:00 Informal meet and greet, registration, load talks
- 8:30 Welcome
- 8:40 Tracing Carbon in Karst Environments in South-central Kentucky to Identify Changes in Groundwater Dynamic Under Varying Landuses
~ Chelsea Ballard, Jason Polk, and Kegan McClanahan
- 9:05 Measurement of Inorganic Carbon Fluxes from Large River Basins in South Central Kentucky Karst
~ Connor Salley and Chris Groves
- 9:30 An Overview of the Reverse Flow Patterns of River Styx in Mammoth Cave, Kentucky: 2009-2012
~ Shannon R. Trimboli, Rickard S. Toomey, III, Kim Weber, and Susan Ryan
- 9:55 Break
- 10:10 The Effect of Faulting on Past and Present Hydrogeology in Long Cave, Mammoth Cave National Park
~ Rickard A. Olson and Rickard S. Toomey
- 10:35 Use of Multiphysics Simulation to Model Environmental Conditions Associated with Bat Hibernacula including Preliminary Indication of Impacts on Saltpeter Vats in Mammoth Cave
~ Aaron Bird, Rick Olson, Rick Toomey, Aaron Addison, and Rachel Bosch
- 11:00 What Data Analytics Can do for You!
~ Leyla Zhuhadar, J. Kirk Atkinson, Albert Meier, and Ouida Meier
- 11:25 Announcements
- 11:30 Lunch - on your own
- 1:00 The Max Kämper Map of Mammoth Cave - A Centennial Restoration
~Tres Seymour
- 1:25 Natural Resource Condition Assessment for Mammoth Cave National Park
~ Cate Webb, Chris Goves, and Katie Algeo
- 1:50 Quantitative Dye Studies to Evaluate the Spill Response System for Mammoth Cave National Park
~ JeTara Brown, Thomas Byl, Rickard S. Toomey, III, and Lonnie Sharpe, Jr.
- 2:15 Break
- 2:25 Modeling Activity of the Indiana Bat (*Myotis sodalis*) at Mammoth Cave National Park using Remotely-sensed Descriptors of Forest Canopy Conditions
~ L. E. Dodd, N. S. Skowronski, M. B. Dickinson, L. K. Rieske, and M. J. Lacki
- 2:50 Citizen Science at Mammoth Cave National Park: Integrating Research and Education
~ Shannon R. Trimboli
- 3:15 Undergraduate Research Projects Help Promote Diversity in the Geosciences
~ De'Etra Young, Shannon R. Trimboli, Rickard S. Toomey, III, and Thomas Byl
- 3:40 Announcements and Closings

Thank You to Our Sponsors!



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McCoy Blue Hole, WKU Green River Preserve

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The Mammoth Cave International Center for Science and Learning is one of a network of nineteen **Research Learning Centers** based in the national parks, where science and education come together to preserve and protect areas of national significance. **Western Kentucky University** has been a valued partner of the National Park Service in this endeavor, supporting research and education at Mammoth Cave.